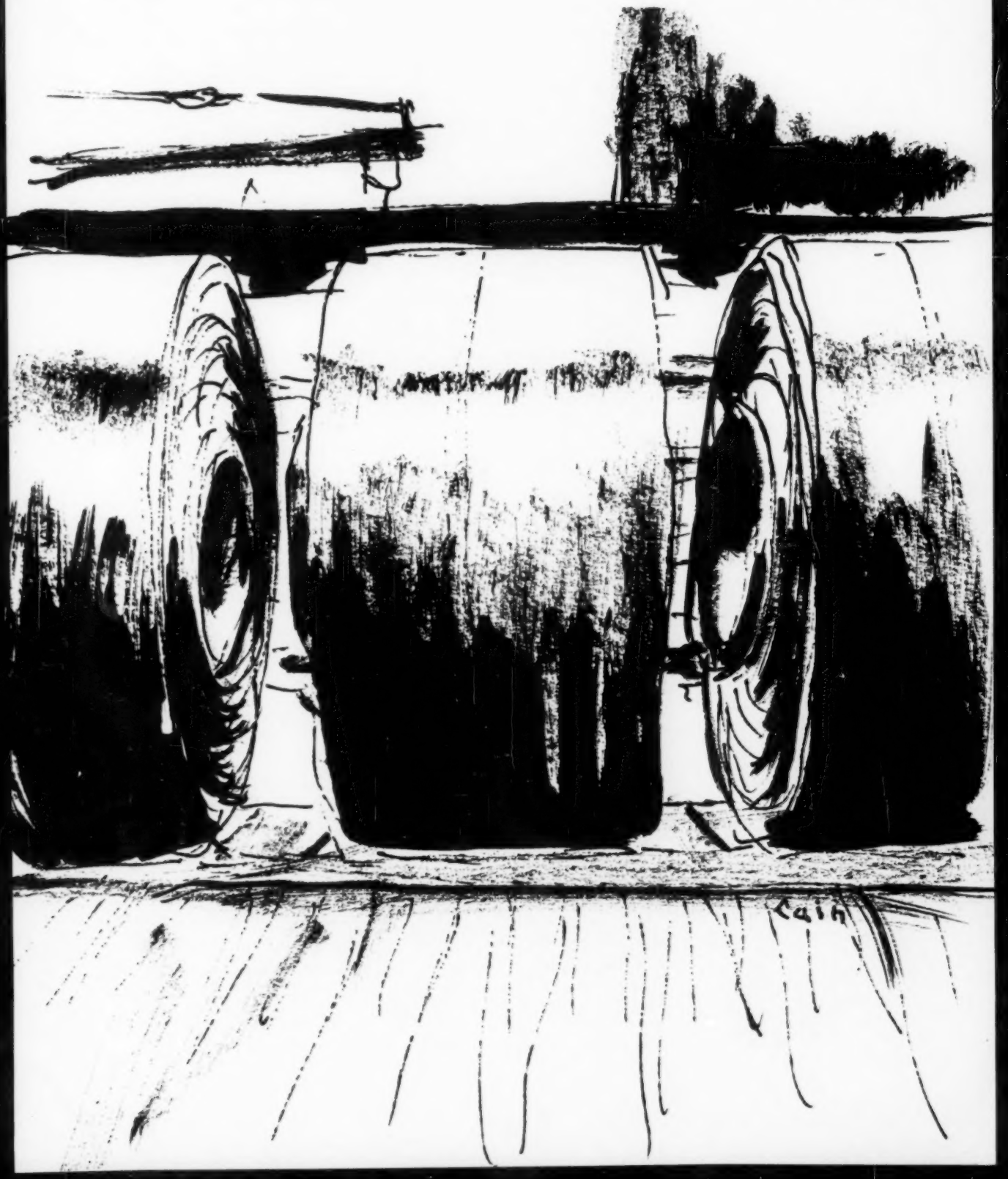
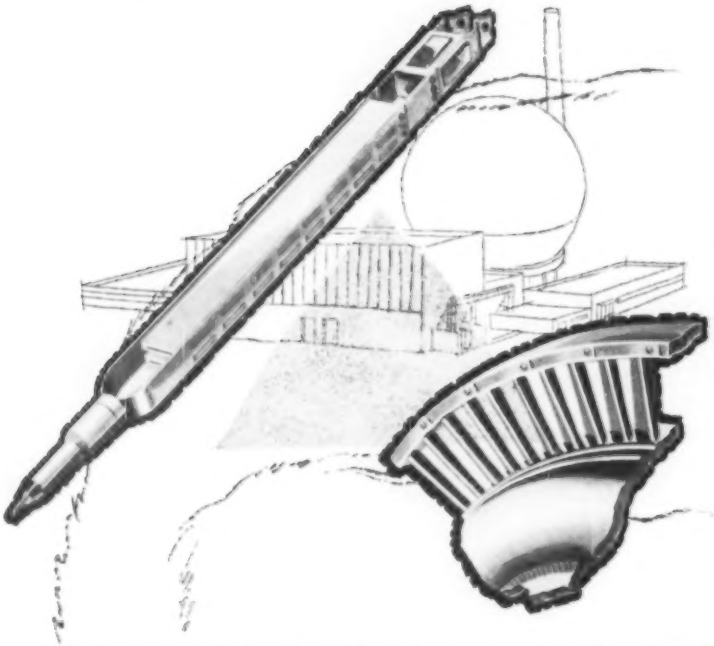
JOURNAL OF

METALS

JANUARY 1960





Today's metallurgical engineers and scientists are constantly meeting the challenge of sweeping technological advances. Electronic brains that solve "impossible" problems . . . jets and space craft which open brand-new horizons . . . reactors that produce fantastic amounts of nuclear energy. Advances such as these *demand* better metals . . . metals free of inclusions, with better electrical conductivity, increased hot strength, extended creep resistance and fatigue limits. In turn, better refractories are a "must" in order to precisely control purity and composition during the development of these metals.

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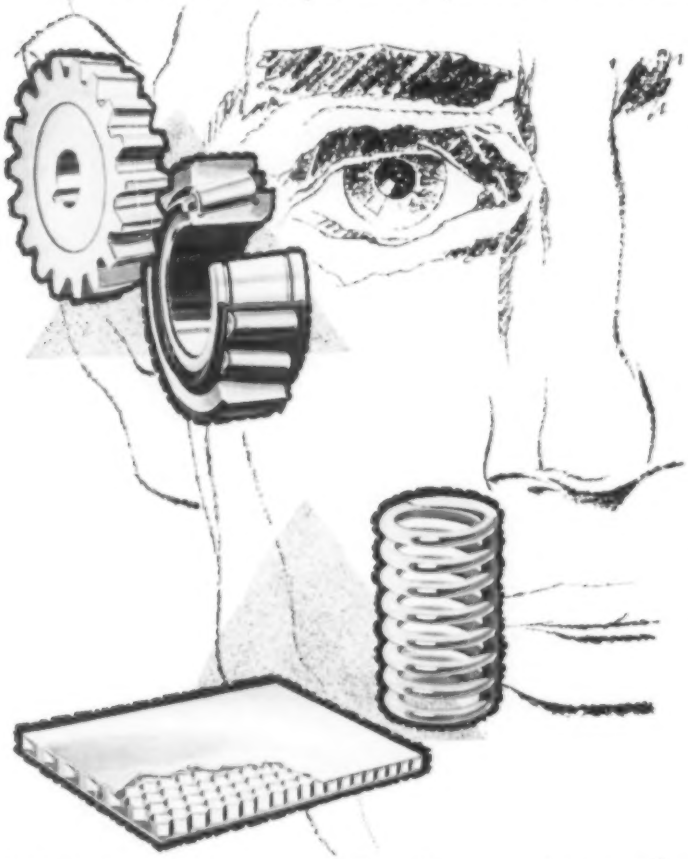

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JOURNAL OF

METALS

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COVER: January is the month of the Second Conference on Flat Rolled Products, described on p. 56. With this in mind, we asked Jones & Laughlin Steel Corp. to allow our cover artist, David Cain, to spend a day at Aliquippa. There he found these steel coils.

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personnel

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• When making application for a position include eight cents in stamps for forwarding application to the employer and for returning when possible.

—MEN AVAILABLE—

All those listed under "Men Available" have membership in the AIME.

Technical Representative for Europe; metallurgist, dipl. Ing., M. Eng. Sc., Swiss citizen, age 48. Four years charge sheet rolling mill; four years testing, failure analysis, metallography; five years process development, quality control; two years advanced research mechanical metallurgy; six years chief-metallurgist and head of quality department steel melting shop, continuous casting (steel) rolling mills, bar and wire drawing, customer contracts. Desires position large American steel producing company interested in European market. English, French, German. Prefer Switzerland. M-221.

Research Metallurgist or **Mine Engineer;** B.S., M.S. (Mine and Metallurgy) Ph.D. (Geologist), age 51. Twenty-five years mine engineer, geologist, mineral exploration, mine development; construction, operation, metallurgical research laboratories; purchase, operation, erection dredges, heavy machinery; design, fabrication bucket drills; X-ray analysis deep welds. Research preferred, inplace flash roasting, leaching laterite nickel chromium ores or submarine anti-detection ejecta as emulsions magnetic colloids. Location: anywhere US, Canada, Mexico. M-1015-Chicago.

Metallurgical Engineer (administrative); B.S. Met. E., age 46. Metallurgical engineer and technical consultant in wire drawing and fabrication mill for 14 years. Metallurgical engineer and instrument manufacturing, 8 years. Experienced most methods of fabricating and finishing of ferrous and nonferrous products. Location desired: Midwest, preferably Michigan. M-1018-Chicago.

Manager of Exploration; M.S. Geology, age 35. Nine years experience reconnaissance and detailed exploration involving both metallic and nonmetallic minerals. Six years supervisory and managerial responsibilities. Experienced open pit operations and engineering. Prefer US. M-1022-Chicago.

General or Project Manager; graduate mining and metallurgy, age 47. Twenty-five years experience in mining, milling, and project engineering in US, South America, Europe, and Australia. Thorough knowledge of management problems. Have operated own company. Salary: $12,000. Any location. Se-1866.

Professor or Geologist; B.S. in Mining Engineering, Ph.D. in Geology, age 44. One year's teaching and geological research for university. Twelve years experience chief engineer and geologist on studies, mapping, reports, exploration; also consultant on tungsten. $12,000. Prefer San Francisco, New York, or foreign Se-1297.

Junior Metallurgist; M.S. in Metallurgical Engineering, age 28. Recent graduate, but has actual experience in drafting, ore dressing, and assaying, with background of X-ray diffraction and ceramics. Salary open. Any location. Se-549.

Mill Superintendent, age 63. Thirty years experience ore dressing research and operation of nonferrous beneficiation plants. Proven ability to cut costs and increase recoveries. Prefer US, Salary open. Se-461.

Plant Manager or Process Engineer; graduate Chemical Engineering, age 47. Professional License, New York. Twenty years experience process engineer, plant manager, chief metallurgist on sponge iron and acid manufacturing and rhenium extraction, nonferrous metal products, aluminum smelting, tin volatilization, test coking coals, and reduction and purification of uranium metal. Salary: $12,000. Any location. Se-1108.

Metallurgical Engineer; graduate, age 32. Eight years metallurgist for zinc and lead smelters. Two years analysis and test at flotation mill. Salary: $8400. Prefer West. Se-488.

Metallurgist; graduate, age 24. One year engineer, develop, improve new and existing metallurgical practices on electric furnace manufacture of ferro and special intermediate alloys, small scale pilot work for refractory. One year production engineering trainee and development for ferro alloy and calcium carbide manufacturing. $7000. Prefer San Francisco Bay Area or West. Se-1214.

Metallurgist; graduate, age 40. Eleven years supervising personnel,

(Continued on page 4)

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Box 2-JM

RESEARCH METALLURGIST is sought as group leader. Advanced degree required or record of technical achievement. Several years of industrial experience necessary, preferably in ferrous metallurgy. The job requires planning of research programs directed toward the use of lithium and manganese in metallurgical applications; phase diagram studies; physical and mechanical properties of alloy systems; chemical properties of alloys. Salary open. Location East.

Box 16-JM

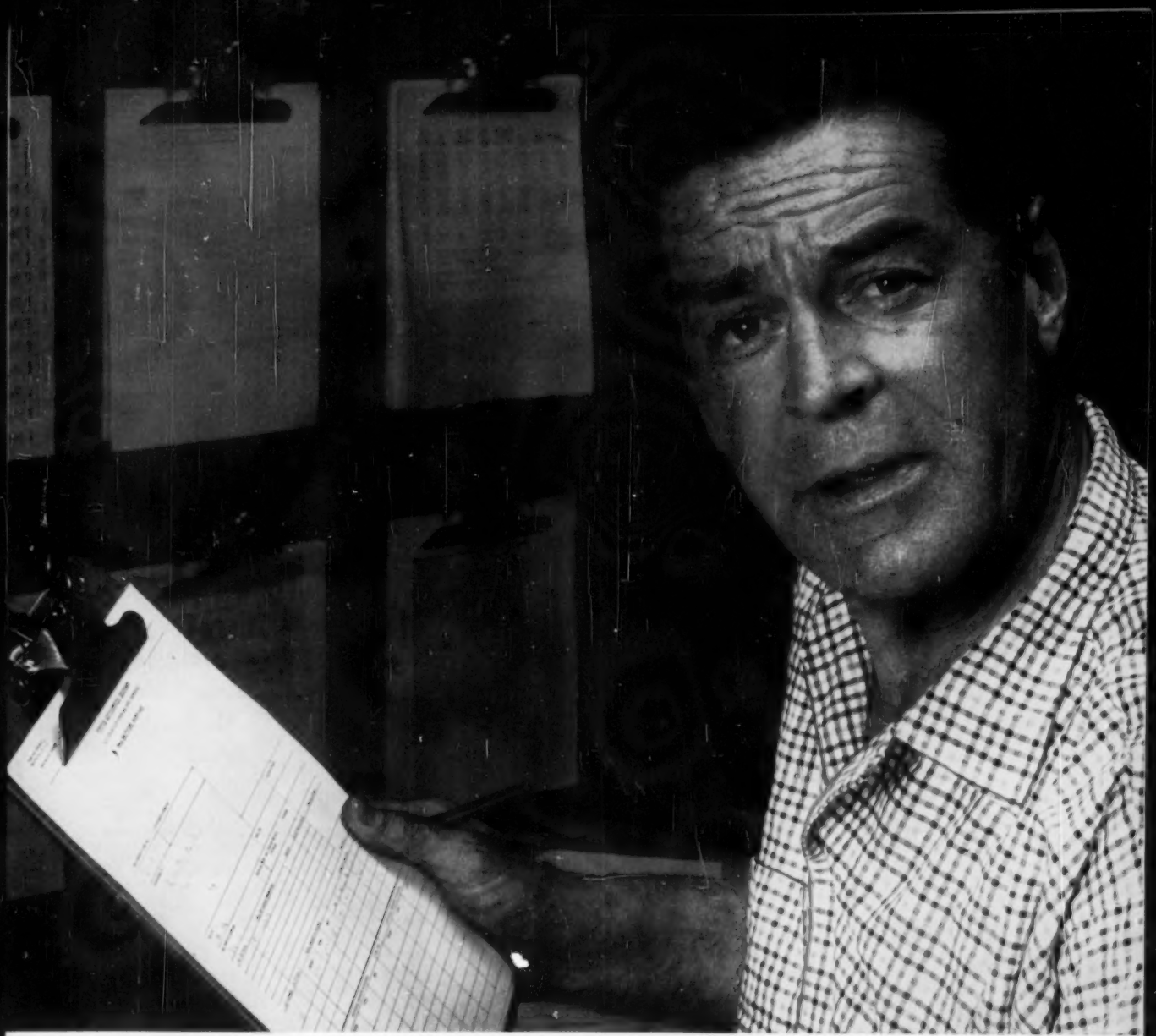
Physical Metallurgist

Opportunity in large Western Pennsylvania research and development organization for recent B.S. or M.S. graduate having sound educational background in physical metallurgy to work on silicon steels for electrical sheets. Applicants with knowledge of X-ray diffraction and crystallography preferred. Experience desirable but not essential. Reply giving complete information and salary requirements to Box 1-JM.

PROFESSORSHIP, MINERAL ENGINEERING. To present courses and conduct research in mine and mill plant design. Rank and salary dependent on qualifications. An advanced degree in mining, metallurgical, mechanical, or electrical engineering and knowledge of mineral industry preferred. Contact Professor E. P. Pfleider, School of Mines, University of Minnesota, Minneapolis.

Graduate and Research Assistantships available starting February, June and September, Metallurgical Engineering. University in New York area. Stipends starting at $1,400.

Box 3-JM



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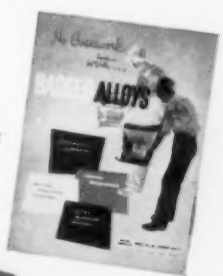

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PERSONNEL

(Continued from page 2)

metallurgy in lead smelters; research on casting techniques at cadmium refinery; foreman at copper refinery; foreman of aluminum rolling mill. $8400. Prefer: California or Northwest. Se-927.

Superintendent; graduate metallurgical engineering age 32. Six years experience head of department (gold, silver refinery, sheet lead and casting), lab assay, safety, personnel, design, labor-management contracts for smelting, refining company. $10,000. Prefer San Francisco Bay Area. Se-583.

Superintendent or Sales; graduate mining and metallurgy, age 45. Extensive experience field work, lab, design, operation of flotation, gravity, chemical plants, sales engineering, and management. $9600 up. Prefer West or Foreign. Se-802.

Designer, graduate mechanical engineering (Scotland), age 45. Twenty-three years charge of sales, engineering, design, contracts, estimates for steel mill construction, furnaces, cranes. Two years industrial engineer, methods, time study, design plant and tools for box manufacturer. Two years civil, mechanical, electrical maintenance on bronze casting and forgings plant. $15,000. Prefer West Coast. Se-1629.

Mill Foreman; graduate mining engineering, age 46. Six years experience, mill shift foreman, classification, flotation, concentration, cyanidation on lead, silver, zinc ore; asst. mine superintendent on underground and surface and assay; mill and mine shift boss on silver, gold and copper mines. $7200. Prefer California. Se-463.

— POSTIONS OPEN —

Process Engineers; mechanical industrial and metallurgical graduates, to be responsible for the improvement of existing processes and equipment; familiar with the economics of a mill's operation. The industrial engineering graduate might be more concerned with the fields of plant layout or tool control. Salaries open. Location: Conn. W8202.

Sales Engineer with at least five years machinery and equipment experience covering finishing and coating of ferrous and nonferrous strip. Various locations in East and Midwest. Salary, $10,000, with bonus. W8175.

Metallurgist-Physicist for major producer of small diameter tubing; graduate metallurgical or physicist, with minimum of one to two years experience, preferably in the field of non-destructive testing. Participation will be in the developments of eddy current methods, ultrasonic tests, and other instrument applications. Apply by letter including salary requirements. Location: Pa. W8150.

Metallurgical Engineer to take charge of production and development; experience in metallurgical vacuum casting desired, hot pressing, and so on. Salary high, opportunities good. Location: northern N. J. W8141.

Analysis Engineer, mechanical or metallurgical, with materials engineering and development experience on heat transfer equipment in power fields. Salary open. Company pays placement fee and relocation expenses. Location: upstate N.Y. W8131.

Agglomeration Engineer; B.S. or M.S. in mineral, metallurgical, or chemical engineering, with three to five years in sintering and pelletizing, preferably of iron ores or concentrates. Laboratory, pilot plant and plant operations experience desirable. For process and economic studies of new and existing techniques. Location: western Pa. W8130.

Sales Engineer mechanical graduate with at least 10 years sales experience on steel mill cold forming equipment. Salary $10,000 year plus. Location: Midwest. W8118.

Chief Metallurgist with degree in metallurgy and 10 to 15 years diversified metallurgical experience, including both ferrous and nonferrous fields (aluminum, brass and nickel silver). Knowledge of tool steels and their applications. Salary $8000 to $10,000 year. Location: Pa. W8096.

Research Metallurgist. B.S. in physical chemistry or metallurgy with Ph.D. or M.S. desired in metallurgy. Interest in research. Will conduct development projects and investigations in physical metallurgy with only occasional supervisory direction as to program or procedure. Salary $8000 to 11,000 year. Company will negotiate fee. Location: Pa. W8090.

Quality Control Director, engineering. Must have 10 years experience in research, development, quality control inspection, know gray iron casting production. Will have full responsibility for control of product quality; answer directly to vice president of operations. Must possess strong metallurgical and foundry background for gray iron casting foundry. Salary $11,000 to 14,000. Employer will negotiate fee. Location: Ohio. C7795.

General Physics Laboratory Director, M.A., preferably Ph.D. for applied industrial research and to conduct experimental investigations of radically new processes and pro-

(Continued on page 6)

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In the important area of metallurgy, immediate openings exist for experienced metallurgists and ceramists to investigate and solve the following types of problems . . . physical and mechanical properties of high-temperature materials and refractory compounds . . . high radiation and ultra high temperature-pressure effects on materials . . . reactor fuel element development and fabrication . . . fuel reprocessing . . . corrosion effects.

In addition to **Metallurgists, Nuclear Engineers, Mathematicians-Programmers**, and Experimental and Theoretical **Physicists** are invited to consider opportunities now existing in varied program areas. Please address your letter of inquiry to Manager of Personnel, P.O. Box 608-R5, San Diego 12, Calif.

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PERSONNEL

(Continued from page 4)

ducts in the field of packaging and utilizing metal, paper, plastic, glass, and other materials. Salary: $12,000 minimum. Employer will pay fee. Location: Chicago. C7805.

Metallurgist graduate with two years experience in general metallurgical work. Will be responsible for metallurgical operations, including laboratory, preparation of tests, alloys, ordering of metals, and so on for manufacturer of precision castings. Salary about $7200, depending on experience. Employer will negotiate fee. Location: Mich. C7814.

Mill Shifter, graduate interested in ore dressing, principally responsible for metallurgical testing and control, also assisting in research in upgrading and smelting problems. Salary open. Location: Mont. Sj-4860.

Sales Engineer, graduate mining engineering or metallurgy. Several years practical experience plus commercial experience selling or purchasing ores and minerals. Represent producing mines supplying iron ore to Japan steel companies. Must be married and preferably with family. Salary open, plus free housing and business expenses. Location: Japan. Sj-4802-R.

Metallurgist, graduate chemical engineering or metallurgy experienced in or aptitude for lead smelting for development, research, and operation. Salary $6000 or more. Location: Midwest. Sj-4785-R.

Research Engineer; M.S. in metallurgical engineering, chemical engineering, or chemistry, or B.S. with exceptionally strong research experience. Must be interested in applying knowledge to solution of industrial problems rather than to fundamental research. Department conducts applied research and development on new processes and major process improvements in fields of mineral beneficiation, hydrometallurgy, and pyrometallurgy. Salary commensurate with training and experience; liberal fringe benefits. Location: West. Sj-4876-R.

Metallurgy Consultant; graduate metallurgist. Must have wide experience in copper smelting and refining, and be familiar with operations and engineering in copper-producing areas throughout the world. To provide technical direction for metallurgical plant and design construction. Also technical assistance to operate smelters and refineries, and handle development work for new methods. Must be top-notch, with sound economic sense, and be capable of contact work under variety of circumstances, including top management. Salary commensurate with experience Headquarters: Mountain States. Sj-4866-R.

new books

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Physical and Mechanical Properties of Nine Commercial Precipitation-Hardenable Stainless Steels, by D. A. Roberts, D. B. Roach, and A. M. Hall, Battelle Memorial Institute—This report, DMIC 112, presents all the physical and mechanical properties available to these Defense Metals Information Center researchers for nine precipitation-hardenable stainless steels—two martensitic, four semiaustenitic, and three austenitic. It is a compilation of data obtained from producers, and no effort has been made to evaluate the various steels' merits or the validity of test data. Two martensitic steels described are Stainless W and 17-4 PH; the semiaustenitic are 17-7 PH, PH 15-7 Mo, AM 350, and AM 355; the austenitic types are A-286, 17-10P, and HNM.

The authors report that "In the annealed (soft) condition, the martensitic types lack the ductility required for extensive forming operations, but can be hardened to yield strengths of about 18,000 psi by simple aging at 900 to 950°F. In the annealed condition, the semiaustenitic types are ductile and readily fabricated. To be fully hardened, complex heat treatments are required. Steels of this type can be hardened to yield strengths in the range of about 175,000 to 225,000 psi depending upon the heat treatment employed. The austenitic types are ductile and readily formable as annealed and can be hardened, by a simple aging treatment at about 1300°F, to yield strengths in the range of 70,000 to 100,000 psi.

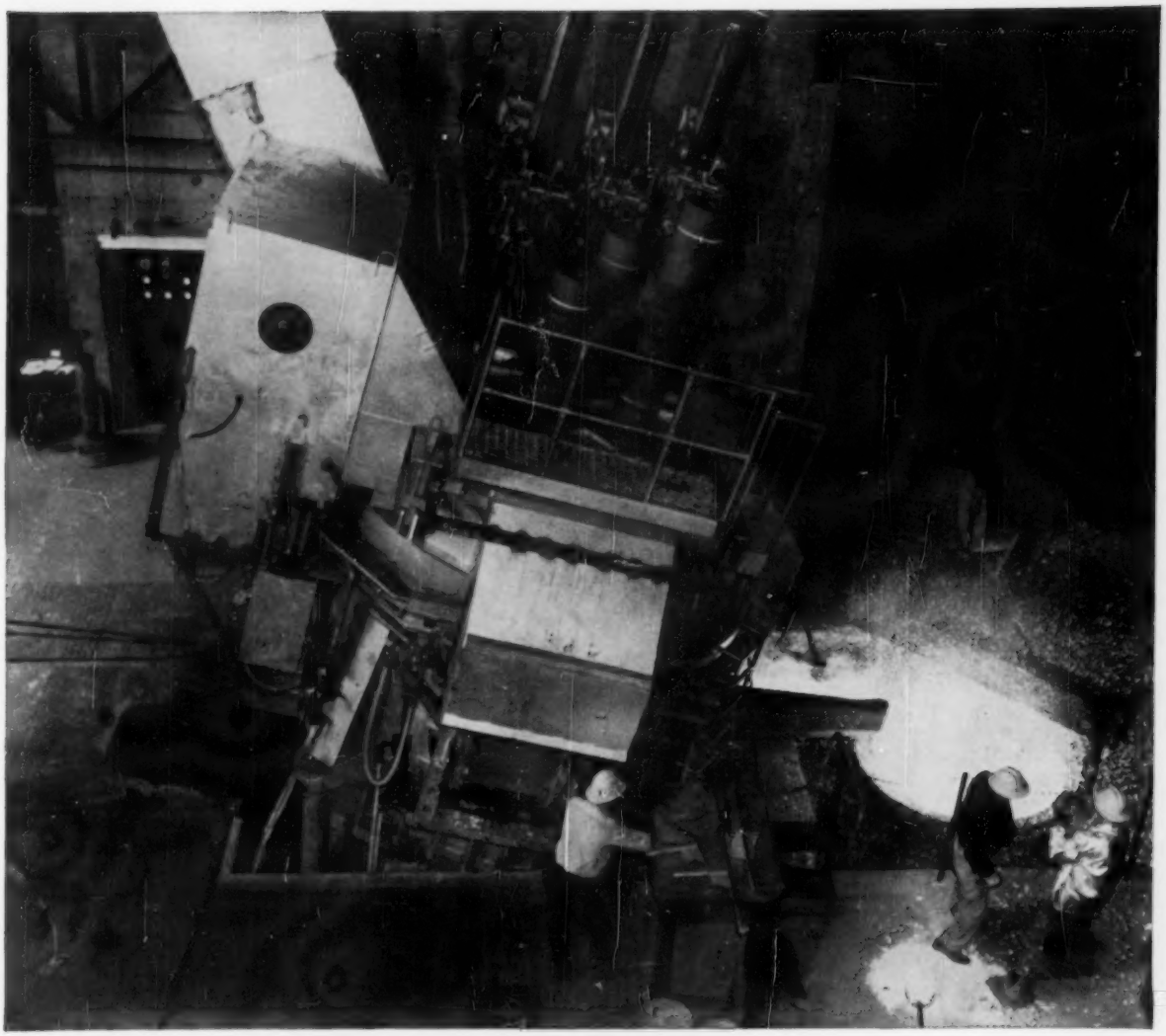
"The austenitic types can be employed at temperatures up to about 1300°F, whereas the martensitic and semiaustenitic types are applicable to temperatures in the range of about 600 to 700°F."

A companion report—DMIC Report 111—presents the physical metallurgy involved in hardening these steels.

To order Reports 111 and 112, write the *Office of Technical Services, Dept. of Commerce, Washington 25, D. C.*

Handbook of Practical Electroplating, by Thomas M. Rodgers, *The Macmillan Co.*, 333 pp., $8.50, 1959—This book is written for both the manager of an electroplating process, and the unversed in the subject. Arranged in encyclopedic form, the

(Continued on page 8)



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BOOKS

(Continued from page 6)

book begins with *abrasives* and ends with *zirconium plating*. In between is to be found a host of information on formulae for basic plating baths, installation and maintenance of equipment, salt-water gilding, and immersion plating. Particular attention is given to the problems of achieving various deccrative colors. Mr. Rodgers, a past president of the American Electroplaters Society, has described each type of plating in terms of its industrial uses, equipment, solution composition, operation, and maintenance and analytical control of solution. •

Radioisotopes for Industry, by Robert S. Rochlin and Warner W. Schultz, Reinhold Publishing Corp. 190 pp., $4.75, 1959—The purpose of this book is to acquaint engineers with radioisotope techniques by illustrating their industrial applications. The book is written so that no previous knowledge of radioactivity or nuclear science is necessary. Also included are discussions on the safety and handling of radioisotopes, as well as setup costs. •

The Fatigue of Metals, by Roger Cazaud, Publisher, *Dunod*, Paris, 592 pp., approx. $14.15, 1959—This is the fourth revised edition of this French language work on fatigue problems. The third edition (1948) was translated into English by A. J. Fenner. It has also been translated into Spanish. Updated now, the book describes all known types of fatigue fracture, while also studying the effect of friction, corrosion, and temperature as factors which cause massive fracture or complete failure. The author explains the selection of suitable metals for parts and machinery construction for strength and safety. The book has particular interest for those who study, build, or utilize machines. •

Grenzschicht Theory (Boundary Layer Theory), 3rd edition, by Hermann Schlichting, *Verlag G. Braun*, Karlsruhe, Germany, 603 pp., approx. $15.45, 1958—In this revision of this standard work on boundary layer theory the following chapters are of particular importance: exact solutions of the steady-state boundary layer equations; thermal boundary layers is laminar flow; boundary layers in compressible flow; origin of turbulence; and the turbulent boundary layer with positive and negative pressure gradient. Chapter reference lists and the general bibliography have also been brought up to date. •

Growth and Perfection of Crystals, edited by R. H. Doremus and others, *John Wiley & Sons*, 440 Fourth Ave., NYC, 609 pp., $12.50, 1958—This book is made up of reports on crystal phenomena, polymer crystallation, and crystallization of simpler molecules, as given at an international conference in Copperstown, N. Y. last year. Organic, inorganic, and polymeric substances are investigated from the standpoint of crystal perfection. . .formation and structure of whiskers. . .presence of dislocations. . .and the mechanism of crystal growth from the melt, solution, and vapor. •

Precipitation From Solid Solution, by R. F. Mehl and others, *The American Society for Metals*, 7301 Euclid Ave., Cleveland, 517 pp., $10, 1959—This work represents, in printed form, a series of lectures presented at the National Metal Congress in November 1957. Among topics discussed are precipitation of hardening-base alloys . . . precipitation hardening of copper alloys . . . precipitation reactions in irons, low-alloy steels, and iron base alloys . . . and precipitation in cobalt base alloys. •

Korosion 11. Kathodischer Korrosionsschutz (Cathodic Corrosion Protection), sponsored by the Deutschen Gesellschaft für Metallkunde, *Verlag Chemie*, Weinheim, Germany, 229 pp., approx. $7.15, 1959—This volume is composed of 10 papers on the general theme of cathodic corrosion protection, given at a Frankfurt meeting last year. It begins with the historical development, then moves to theoretical principles; the concept of cathodic protection against both fresh and salt water; underground corrosion of both piping systems; stray-current corrosion; measurement techniques; and so on. •

Development of Active-Eutectoid Base Alloys, by R. F. Bunshah and H. Margolin, for Wright Air Development Center, US Air Force. Order *PB 151518* from the *Office of Technical Services, Dept. of Commerce, Washington 25, D. C.*; 51 pp., $1.50, 1958—This report by two New York University AIME members probed the active eutectoid titanium alloy system, where decomposition of the beta phase to alpha plus compound occurs very rapidly. An alloy of Ti-6Cu-7Al-6Zr possessing a tensile strength of 108,900 psi at 1200°F was outstanding among several showing promise in the 1000° to 1200°F range. In the study, titanium-copper base alloys were systematically alloyed with alpha-strengthening additions of aluminum and/or tin and/or zirconium. The Ti-6Cu-7Al-6Zr alloy also showed tensile strength of 165,000 psi in the annealed condition at room temperature. The drop-off in tensile strength with increasing temperature was found to come above 1000°F in this type of alloy—a factor which increases its high-temperature use potential. Rupture life at 1000° was also found to be very good. The best strengthening agents were aluminum, copper, zirconium, and tin, in that order.

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personals

Edgar C. Bain and **Earl C. Smith** received honorary memberships in the American Society for Metals in ceremonies at the National Metals Exposition and Congress in November. Dr. Bain is the retired asst. vice president of operations for U.S. Steel Corp. Mr. Smith is now chief metallurgist and research head of Republic Steel Corp. These were only the 25th and 26th such honorary memberships awarded by the ASM in its history.

Matthew A. Hunter received the 1959 Gold Medal of the ASM in other ceremonies. Dr. Hunter is Dean Emeritus of Rensselaer Polytechnic Institute.

John E. Dorn, Frank E. Hauser, and **Philip R. Landon**, of the University of California were also among award winners. Bestowed on them was the Society's Henry Marion Howe Award, for joint authorship of a paper on *Deformation and Fracture of Alpha Solid Solutions of Lithium and Magnesium.*

A. B. Kinzel is the recipient of the Industrial Research Institute's Medal for 1960. The award is made for "outstanding accomplishment in leadership or management of industrial research which contributes broadly to the development of industry or the public welfare." Dr. Kinzel will receive the medal at the Institute's Annual Meeting next May.

William P. Getty and **James B. Austin** took part in the Pittsburgh technical meeting of the American Iron and Steel Institute in October. Mr. Getty, asst. vice president of production, Jones & Laughlin Steel Corp., presided at the afternoon session. Dr. Austin, administrative vice president, Research and Technology, U.S. Steel Corp., presented a paper on *Non-destructive Testing in the Steel Industry.*

L. F. Coffin, Jr., R. M. Goldhoff, and **N. J. Grant** were among participants at the Annual Meeting of the American Society of Mechanical Engineers (ASME), Nov. 30-Dec. 4. Dr. Coffin, of the General Electric Co., authored a paper on *The Stability of Metals Under Cyclic Plastic Strain.* Dr. Goldhoff, also of G.E., gave *Some Observations on the Extrapolation of High-Temperature Ferritic Steel Data.* Dr. Grant, professor of metallurgy at the Massachusetts Institute of Technology, co-authored two papers with Robert Widmer, also of MIT. *The Creep-Rupture Properties of 80 Nickel-20 Chromium Alloys;* and *The Role of Atmosphere on the Creep-Rupture Behavior of 80 Nickel 20-Chromium Alloys* were the titles of the papers.

David P. Moore, Sr., has been appointed supervisor of Quality Control at the Louisville, Ohio, plant of Jones & Laughlin Steel Corp.'s Stainless and Strip div. Mr. Moore was formerly service metallurgist at the plant.

J. L. Kimberley and **S. F. Radtke** were instrumental to the program planning for the American Zinc Institute's November *Symposium on Plating of Zinc Die Castings.* Mr. Kimberley was chairman of the opening technical session, while Dr. Radtke provided the recapitulation at the end of the meeting.

Frank W. Chambers is now executive vice president of Strategic Materials Corp., Buffalo, N.Y. He resigned his position as director of engineering, Kennecott Copper Corp., in order to accept the new post.

Arthur Elsea recently celebrated his 20th anniversary with Battelle Memorial Institute. In recent years there his primary concern has been the study of glass grinding and polishing, although his reputation in metallography is also widespread.

Gilbert R. Rothschild will be among the contributors to the sixth annual Midwest Welding Conference, meeting at the Illinois Institute of Technology Feb. 3-4, 1960. Mr. Rothschild is asst. director of metallurgical research, Air Reduction Co., Inc. Title of his paper is *Fundamentals of Inert Gas Welding.*

Don B. Jugle has joined the staff at the Argonne National Laboratory as an asst. metallurgical engineer in the Metallurgy div. He received a B.S. in metallurgy from Columbia University in June, and worked at the Laboratory last summer as a student aide.

M. W. Lightner was one of the guest speakers at the Founders' Society of America's 57th Fall Meeting in September. Dr. Lightner, vice president of applied research U. S. Steel Corp., spoke on *Looking Ahead in Steel Research.*

Robert F. Mehl has been granted a temporary leave of absence from Carnegie Institute of Technology in order to become a consultant for scientific liaison between U. S. Steel Corp. and European research organizations and universities. Dr. Mehl is to be headquartered in Zurich, Switzerland.

R. L. Wachtell of the Chromalloy Corp. was among the participants at an Aerospace Finishing Symposium in December, sponsored by the Southwest Society of Aircraft Materials & Process Engineers. Mr. Wachtell spoke on *Surface Protec-*

(Continued on page 12)

JUST PUBLISHED

THERMOCHEMISTRY FOR STEELMAKING

Volume I

By John F. Elliott and Molly Gleiser, M.I.T.

A collection of tables and charts on the high-temperature chemistry of iron and steelmaking, designed to be useful in both laboratory and plant. Contains up-to-date information, mutually consistent with regard to base states, reference states, etc., on physical and thermochemical properties of selected elements, standard heats and free energies of formation of selected compounds (inorganic carbides, nitrides, oxides, phosphides, silicides, and sulfides), and vapor pressures of selected elements and compounds.

It is the foundation stone of a series of several volumes to be issued during the next few years, as part of a program sponsored by the American Iron and Steel Institute to consolidate, summarize, and present in readily accessible form all pertinent data on the physical chemistry of steelmaking.

296 pp. 26 illus, 8½ x 11, 1960—$10.50

ELEMENTS OF PHYSICAL METALLURGY

By A. G. Guy, *Purdue Univ.*

"A useful addition to the library of the practicing metallurgist, since it presents the fundamentals in a very readable manner and covers the latest concepts of dislocation theory." ***Science***

528 pp. 297 illus, 2nd ed. 1959—$10.50

ELEMENTS OF MATERIALS SCIENCE

An Introductory Text for Engineering Students

By L. H. Van Vlack, *Univ. of Michigan*

"Treats materials from a broad and scientific viewpoint. Although designed as a text aimed at engineering students, there is much to be learned from it by the metallurgist who has not studied ceramics, organic materials, etc."

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528 pp. 550 illus, 1959—$8.75

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► Advanced study in nuclear science is offered by the Atomic Energy Commission's newly established International Institute of Nuclear Science and Technology. The Institute is an expanded version of its former International School, located at the Argonne National Laboratory. It is designed to give advanced and specialized training in nuclear science not yet available in colleges and universities.

A post-graduate curriculum will be presented at two levels. The *participant* level will require the equivalent of a M. S. from an American university, with some background in fundamental nuclear studies. A one or two 16-week semester program may be elected, depending upon the participant. Tuition is $1000 per semester. An *affiliate* level candidate will require the equivalent of a Ph.D. At least two semesters work must be done on this level, for it is expected that affiliates will make a significant contribution to Argonne's research program. No tuition is charged on this level.

Both foreign and American students will be admitted for study. For further information, write: *Division of International Affairs, Atomic Energy Commission, Washington 25, D. C.*

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Slip Casting Research

► A total of $400,000 in Government and industrial contracts has been awarded Stevens Institute of Technology for research into the slip casting of metallic components.

The new contracts cover work on fuel elements for use in nuclear power reactors . . . developing new techniques for economically producing components of metals and alloys with excessively high melting points . . . and producing, from steel alloys, parts which will be subjected to high stresses.

Aiding in the research is Stevens' new $30,000 vacuum furnace, which is heated to 2500°F for initial experiments and gradually fired to 4400°F. Plans are also underway for an additional furnace which will be designed to heat metals in an atmosphere of hydrogen gas.

Gregory J. Comstock heads the research carried out by the powder metallurgy laboratory.

Research at Arizona

►A detailed account of the University of Arizona's research projects has recently been published to commemorate the 75th anniversary of the University's founding. Metallurgy takes a prominent place in both present and future plans at the University.

Construction of a solar furnace is underway for use in studying the behavior of metals and ceramics at temperatures up to 6000°F. When completed, the 60-in. parabolic instrument will duplicate, on a small scale, the intense heat created by atmospheric friction.

A project with spage-age applications is that of aluminum-magnesium alloys, being sponsored by the US Army Ordnance Dept. Tensile strength testing procedures are being used to determine regions of weakness and unusual behavior in the alloyed metals. These regions will then be further explored by high-power microscopy.

A leader in extractive metallurgy research on the campus is John B. Cunningham. One of the projects concerns fluidizing reactors and their applications. Another study is probing the uses of hydrogen peroxide, especially in flotation applications and in uranium mining. A co-operating program between the University and the US Bureau of Mines is now entering its sixth year, with fundamental research in the leaching of metals at elevated pressures and temperatures now being conducted.

Copies of the 88 pp. report are available without charge from the University of Arizona Press, Tucson, Ariz.

letters

to the editor

Likes Tungsten Review

Congratulations on the latest issue of your section "Phases and Processes". (November, pp. 763-764). Mr. Tietz must have spent considerable time reading and abstracting the literature. Being one of the many people receiving a look at current research on tungsten from your article without spending the many hours devoted by Mr. Tietz, I would like to express my appreciation and hope to see more "Phases and Processes" as prepared by Mr. Tietz.

L. M. Bianchi
Supervisory Engineer
Westinghouse Electric Corp.

Books

► *American Standard Illustrations for Publication and Projection*, published by the American Society of Mechanical Engineers, 14 pp., $2. 1959—This standard, approved in April, supersedes two earlier overlapping versions. Its chief virtue is the basis it does provide in the sizing and representation of line drawings and tabular illustrations, the two forms to which it specifically alludes. The standard codifies much of the material found in books on production and illustration, but uses a strict engineering mechanics viewpoint.

Copies of *American Standard Illustrations for Publications and Projection*, Y15.1-1959, The American Society of Mechanical Engineers, 29 W. 39th St., New York 18.

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YOUR MAGAZINE

This is your magazine. You read it (we hope). You write many of the articles appearing in it. Through the Advisory Subcommittee we have tried to sample your opinions and create the magazine you want. Furthermore, we have been asking you to write to us, commenting on editorial policy or on matters more specific. We have been publishing these letters.

As with any function of The Metallurgical Society, this magazine can be only what you make it. The staff puts out the magazine, but without direction from our readers as to what is wanted, we are really just "shooting in the dark." Without both opinions and help from our readers—opinions as to what you want to see in the magazine and help in getting material to us—we can only guess what is wanted and draw from our own experiences in collecting material.

During 1959 we wrote to more and more of you. To some we asked the writing of an article on a specific subject. To others we asked the giving of knowledge to your fellow readers via writing for Phases and Processes. More recently, we have been writing to you in an effort to set up an effective system for reporting on the myriad of technical sessions of the Annual Meeting.

Yes, this is your magazine. And its coverage depends a great deal on you. We can fill in by writing in certain areas, but in many other areas it is up to you. During 1960 we expect to publish more pages and more effectively cover developments in metallurgy and related fields. Our success largely depends upon you.

It is your magazine. Help us to make it what you want.

F. Weston Starratt

PERSONALS

(Continued from page 9)

tion of Metals for Atmospheric Reentry by the Diffusion Technique.

Bruce Dunnington spoke on the design of capsules to hold small specimens for irradiation at the American Nuclear Society conference in Washington last November.

Robert L. Cleveland has been appointed president of the Tonawanda Iron div., American-Standard. For the previous year, he had been general manager of the division.

Paul Queneau delivered the 30th Warren Lecture at the University of Minnesota Institute of Technology in October. Mr. Queneau, vice president of The International Nickel Co., Inc., spoke on the selective reduction process used at The International Nickel Co. of Canada, Ltd. Mr. Queneau, an active AIME member, is chairman of the Extractive Metallurgy Division's Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt, which will take place at the Annual Meeting in February.

Thomas F. Arcoleo has joined Avco Research and Advanced Development, Wilmington, Mass. There he assumes the position of asst. engineer in metallurgy. He was formerly an asst. project engineer with the Vanadium Corp. of America.

Henry S. Hall has been appointed manager of the Combustion Control div. of Morgan Construction Co., Worcester, Mass. He succeeds **Strickland Kneass, Jr.,** who has been made a consultant with the company. Mr. Hall was formerly with Lukens Steel Co. **John J. Webber** has been named his assistant. Mr. Webber was previously a sales engineer with the Harbison-Walker Refractories Co.

Edward L. Badwick is now plant manager at Accurate Specialties Co., Inc., semiconductors component manufacturer in Hackensack, N. J. Mr. Badwick was formerly a production engineer with Bendix Aviation Corp.'s semiconductor div. at Long Branch, N. J.

D. E. Thomas is now in charge of metallurgy at Westinghouse Electric Corp.'s new Astronuclear Laboratory. Dr. Thomas was formerly manager of Naval Reactor Metallurgy at Westinghouse's Bettis Laboratory.

Archie J. MacDermid, founder of MacDermid, Inc., Ferndale, Mich., has announced his retirement from executive duties with the sale of his interests to the company and its employees.

C. C. Whiting, Jr., has been named manager of chromium product production at Union Carbide Metals Co., div. of Union Carbide Corp. Previously, he was plant metallurgist at the Company's Alloy, W. Va., plant.

Phillip J. Maddex will direct the corporate engineering activities of U.S. Borax & Chemical Corp., in his new position as chief engineer. He will be based at the Company headquarters in Los Angeles. Mr. Maddex was formerly manager of the Henderson, Nev., plant of the Titanium Metals Corp.

Robert L. Novak is now attending graduate school at the University of Philadelphia under a fellowship, while working toward his Ph.D. in metallurgy. He was formerly a member of the technical staff at RCA Laboratories.

William H. Feathers has been appointed to the presidency of National Carbon Co., subsidiary of Union Carbide Corp. The promotion came with a shift in executives in the formation of a new Corporation operating division for consumer products, Union Carbide Consumer Products Co. Mr. Feathers had been vice president and general manager in charge of industrial products at National Carbon.

William H. Magruder is now supt. of major alloys at the Ashtabula,

(Continued on page 62)

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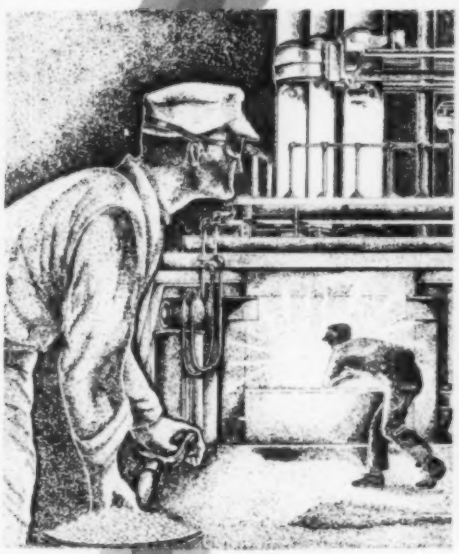

AN IMPORTANT MESSAGE FOR ELECTRIC STEEL FURNACE OPERATORS

The performance requirements of graphite in nuclear and space age applications are spurring advances in graphite technology that were unheard of a few short years ago.

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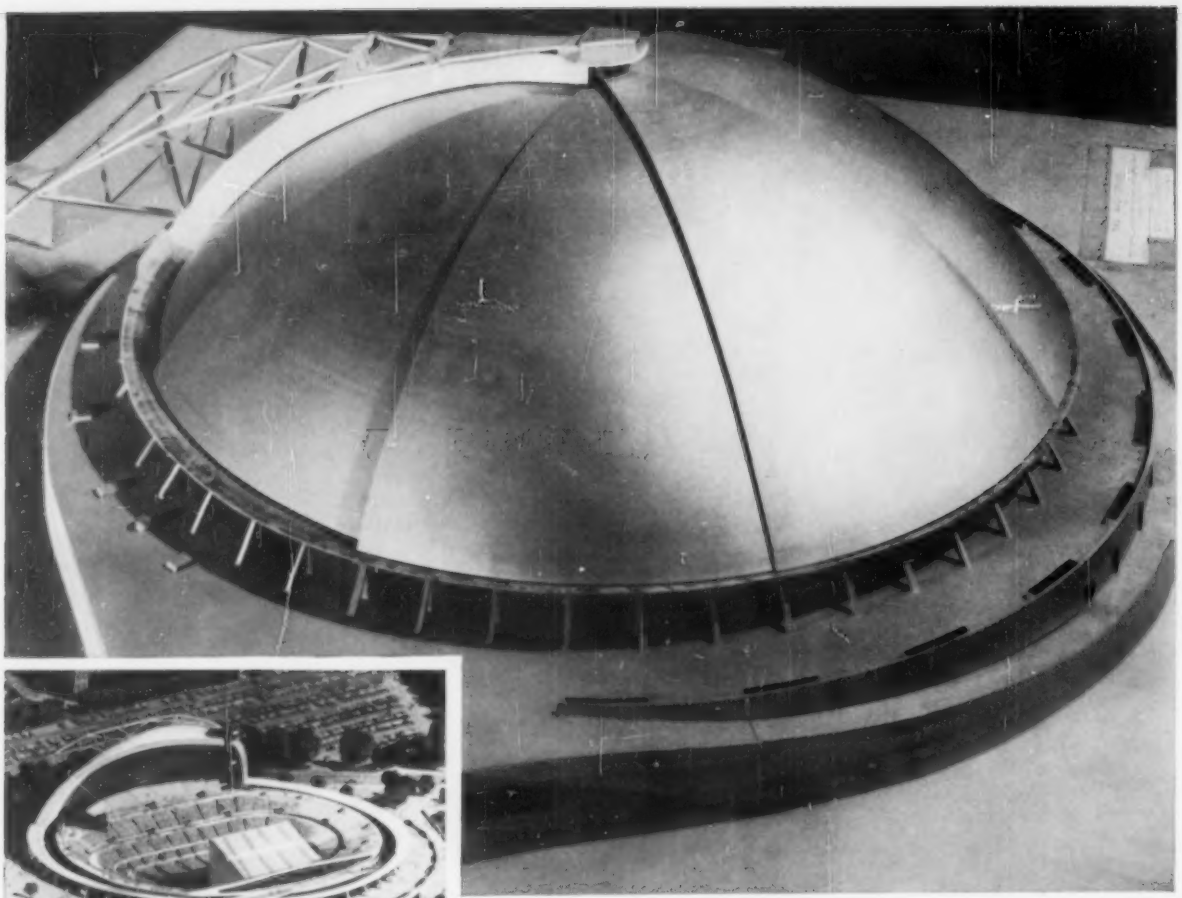

All-weather auditorium in Pittsburgh will be covered by a 415-foot diameter Nickel-containing stainless steel dome. Largest of its kind in the world, the dome will protect an audience of more than 13,000.

"Push-button umbrella roof" of stainless steel gives Pittsburgh a new all-weather auditorium

Watching a play or listening to music under the stars heightens the enjoyment. That is, until a passing shower comes along to wash out the fun. But now comes a new idea in auditoriums. In this one, an umbrella roof of Nickel-containing stainless steel will close at the first drops of rain—and on with the show.

It's a simple concept, but a daring one. Eight huge sections nest together when the dome is open. Push a button, and six of these sections glide quietly together around an outside track.

They looked into all sorts of sheathing materials in designing the dome before choosing stainless – a Nickel-containing stainless steel.

For stainless with Nickel in it is one of the most weatherproof metals there is. It is corrosion-resisting all the way through – in salt air as well as industrial atmospheres. What's more, it's virtually self-cleaning – rainfall alone keeps this metal clean.

No wonder you see Nickel-containing stainless wherever strength, long life and handsome appearance are called for! Not only in buildings – inside and out – but everywhere you look.

Suggest something to you? Can stainless help you solve a problem involving corrosion, stress, appearance, temperature extremes? The way to find out is to write us. We'll see if Nickel-containing stainless steel – or some other nickel alloy – may be just what you're looking for.

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W ingots made 'indirectly'

A process for producing tungsten ingots weighing up to 250 lb has been achieved by indirect sintering. Development of the process was under the direction of Paul Schwarzkopf, president of the Schwarzkopf Development Corp., New York, and Metallwerk Plansee, Reutte, Tyrol, Austria.

The procedure, developed at the Metallwerk Plansee laboratories, permits the production of large components from tungsten alloys, as well as pure tungsten. Tungsten powder is compacted into ingots of sizes such as 8 in. x 16 in. x 25 in., then sintered in large-capacity furnaces, forged to preforms at high temperatures, and finally sintered to finished parts.

Compacts up to 250 lb can be sintered in tiltable push-type furnaces, while batch-type furnaces must be used for larger components. The aim is to produce sintered ingots of dimensions comparable to standard-size steel ingots. Demands for larger tungsten parts in the rocket and missile fields will especially benefit from the development.

Vanadium research spurred

Five US Bureau of Mines experimental stations and laboratories will be engaged in research on vanadium during 1960. Studies will be conducted on the preparation of vanadium compounds for reduction to high-purity metal, and on the effects of impurities on the properties of the metal and its alloys. Also scheduled is research on electrorefining in fused-salt baths to produce a high-purity metal. Other research will involve studies of ways for producing commercial-grade or quality ductile metal. The development of analytical techniques to determine minute quantities of impurities in high-purity vanadium will also be included.

Magnetic metal films probed

Thin magnetic metal films may provide the answer to the components of memory systems in making high-speed computers work even faster, says a Case Institute of Technology physicist. In speaking before the November meeting of the American Physical Society, Dr. Richard W. Hoffman observed that such films (as little as 50 atoms thick) can be prepared by evaporating metals, such as iron, nickel, and their alloys, in a vacuum. Below certain temperatures, such as 600°F, the films may become spontaneously magnetized. Furthermore, magnetic patterns in the film can be changed very fast. When this is done, a small voltage is generated which can provide a signal for a computer. It is this property which makes such films of potential value as a *memory* in modern high-speed computers.

Soviet ups metallurgy budget

The 1960 budget for the Soviet Union includes a 20 pct increase in metallurgy expenditures. Aleksei N. Koskygin, the country's planning chief, released the figure with the notice that total spending on science would be 15.4 pct over 1959.

He also gave the following 1960 goals for major industries: steel—64,900,000 tons; iron ore—105,000,000 tons; oil—144,000,000 tons; electricity—291,150,000,000 kw hr; natural gas—53,000,000,000 cu m.

Inco announces nickel steels

A family of 25 pct nickel steels which bear high strength properties have been developed in the research laboratories of International Nickel Co., Inc. It is reported that the nickel-steels can be air cooled from the heat treating temperatures, quenching being unnecessary.

Yield strengths in excess of 250,000 psi with 6 to 10 pct elongation and more than 20 pct reduction of area are attainable. The family of steels is the product of research by C. G. Bieber of Inco.

Copper crucible called 'feasible'

Use of a water-cooled copper crucible for induction melting reactive metals such as titanium has been declared technically feasible by a group of Battelle Memorial Institute scientists. Describing their study for Mallory-Sharon Metals Corp., they felt that the new process could have far-reaching effects on the production of special metals. The announcement closely followed Mallory-Sharon's receipt of a contract from the Air Materiel Command to build a prototype cold crucible for induction melting.

Describing the situation, George H. Schippereit, Battelle metallurgist, said there were two principal problem areas. First, is the tendency of the metal crucible to become too hot, thus contaminating the charge or damaging the crucible itself. Second, there were electrical power losses within the crucible which could seriously reduce the melting rate.

Studying these and other factors, Battellites designed a special segmented copper crucible. Discussing possible advantages of cold-crucible melting over the consumable-electrode furnace, Mr. Schippereit pointed out that the new process does not require a specially prepared electrode. The cold crucible will accept all types of raw material, including scrap metal. The experimental process lends itself to continuous melting and casting of ingots, or casting directly from the crucible, he noted. According to Schippereit, the cold-crucible process should produce consistently high quality metal in a single melt, because vigorous stirring action, characteristic of induction melting, makes for a homogeneous metal.

REPORTER

Rare earth salt cleans steel

Development of a rare earth salt, called *Didymium Fluoride*, is said to produce 50-ton heats of clean bearing steel consistently. This improvement, developed by Metallurgical Enterprises of Buffalo, N.Y., is reportedly of such magnitude to compete with vacuum melting.

Refractory subsidiary formed

The formation of Harbison-Carborundum Corp. has been announced. The Falconer, N. Y., based facility is the product of agreement between Harbison-Walker Refractories Co. and Carborundum Co. The subsidiary will be engaged in the engineering, manufacture, and sale of fused refractories. The fused refractory lines of Harbison-Carborundum will include alumina, chromite, and zirconia-base refractories for the glass industry; chromite and magnesia-base refractories for the steel industry; cements and other auxiliary products for fused refractory applications; and other fused refractories.

The plant is Carborundum's recently modernized facility. Additional facilities are contemplated for the manufacture of chromite magnesia-base fused refractories at a location not yet announced.

Boron compressed for crystals

Production of large crystals of boron for semiconductor experiments has been effected by Bell Telephone Laboratories researchers through use of a new powder compression techniques. The technique uses high-melting-point boron, which has both metallic and nonmetallic properties; subsequent floating-zone refining gives it commercial possibilities.

In the technique, boron powder —20 to 100 mesh in size is treated in a boiling boric acid solution. The resulting powder is then pressed into forms which can be handled without breaking. The formed compacts are then heated in two stages under vacuum to decompose the boric acid into boron oxide. This compound forms a liquid coating on the boron particles. When the compact is cooled, this liquid hardens, and bonds the powder into a strong bar.

The bar of boron powder is vertically mounted for floating-zone melting through an induction coil. During the operation, the boron oxide sublimes before the melting point of boron (about 2000°C) is reached. Crystals as large is 0.1 in. are obtained.

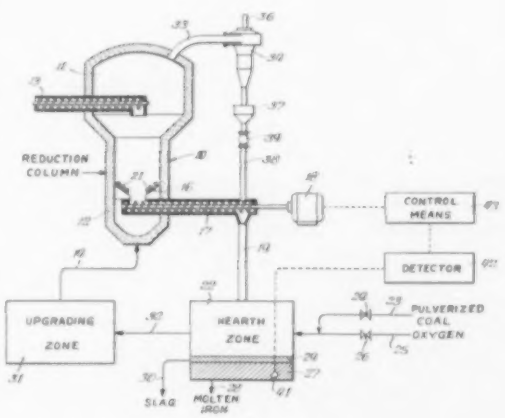
Direct reduction—new entry

Several years of experimental work on gaseous reduction of iron ores has culminated in the patent no. 2,889,219 issued to James W. Halley and assigned to Inland Steel Co.

As shown in the figure, a screw conveyor mechanism, 13, takes subdivided or granular iron oxide ore from a supply or preheating source (not shown) and brings it into the enlarged refractory-lined column. Carbon-monoxide-rich reducing gases come from a line, 14, to the bottom of the reduction column, 10. Moving downward against the upwardly flowing reducing gases, the ore solids are supported at the base by a truncated partition, 16. Bubble-cap elements, 21, protect gas passages. A motor, 18, drives the screw conveyor, 17, which moves the reduced ore solids from the reduction column to a feed hearth line, 19.

The ore solids, which are composed of reduced iron, gangue, and some unreduced iron oxide, pass from the feed line to the hearth zone, 22. The zone combines melting and gas generating and burns a high-oxygen gas. The CO_2:CO ratio in the exit combustion gases is maintained so that the gases in the hearth zone are oxidizing to iron. Thus, a 2900° to 3500°F temperature, sufficient to separate reduced ore particles from the gangue, is obtained. Molten iron, 27, is removed from the hearth zone through a line, 28, and a fluid slag, 29, formed from the ash in the coal and the gangue in the ore, is removed through a line, 30.

Since the combustion gases produced in the hearth zone contain an excess of CO_2, they must be subjected to an enrichment treatment before they can be used for ore reduction. This is preferably done by reducing the CO_2 content in reaction with carbon. The depleted reducing gases pass from the top of the reduction column through a line, 33, to a cyclone separator, 34, where fine ore particles are removed. The off-gases are discharged through a line, 36, and the ore fines collected in a hopper or storage vessel, 37, connected by a line, 38, and valve, 39, to the discharge end of the screw conveyor, where the ore fines may be discharged through the hearth feed line to the hearth zone.



Papers Accepted for the TRANSACTIONS

Stress Induced Strain Aging, by J. O. Brittain and S. E. Bronisz (IMD)

The Solubility of Carbon in α-Fe as Determined by the Time Decay of Permeability, by Joseph Singer and E. S. Anolick (IMD)

High Conductivity Copper-Rich Cu-Zr Alloys, by Matti J. Saarivirta (IMD)

The Self-Diffusion of Columbium, by R. Resnick and L. S. Castleman (IMD)

Effect of Manganese on the Austenite-Pearlite Transformation, by M. L. Picklesimer, D. L. McElroy, T. M. Kegley, Jr., E. E. Stansbury, and J. H. Frye, Jr. (IMD)

Critical Recrystallization of Zirconium, by J. C. Bokros (IMD)

Deformation and Fracture of Magnesium Bicrystals, by J. D. Mote and J. E. Dorn (IMD)

An Extruded Chromium-Alumina Alloy, by A. Gatti (IMD)

Diffusion Studies in the Uranium-Niobium (Columbium) System, by Norman L. Peterson and Robert E. Ogilvie (IMD)

Kinetics of Nickel Corrosion in Sulfuric Acid, by Charles H. Pitt and Milton E. Wadsworth (IMD)

Activity of Oxygen in Liquid Iron-Phosphorus Alloys, by Daniel Dutilloy and John Chipman (ISD)

A New Correlation of Blast Penetration in a Blast Furnace, by G. C. Gardner (ISD)

Mechanical Properties of Magnesium Monocrystals, by W. F. Sheely and R. R. Nash (IMD)

Nature of the Matrix for Secondary Recrystallization to the Cube Texture in High-Purity Silicon Iron, by C. G. Dunn and J. L. Walter (IMD)

On the Widmanstätten Habit Plane of Proeutectoid Cementite, by R. W. Heckel, J. H. Smith, and H. W. Paxton (IMD)

Plastic Deformation of Aluminum Multicrystals, by C. Elbaum (IMD)

Thermodynamic Interaction Parameters of Elements in Liquid Iron, by M. Ohtani and N. A. Gokcen (ISD)

Precipitation Processes in Mg-Th-Zr Alloys, by L. Sturkey (IMD)

Sulfating of Cuprous Sulfide and Cuprous Oxide, by Milton E. Wadsworth, K. L. Leiter, William H. Porter, and John R. Lewis (EMD)

New Tough Pitch Continuous Copper Melting and Casting Unit at Asarco's Perth Amboy Plant, by G. D. Storm and J. R. Stone (EMD)

The Tensile Fracture of Ductile Metals, by H. C. Rogers (IMD)

The Solubility of Hydrogen and Nitrogen in Liquid Binary Alloys of Iron, Nickel and Cobalt, by T. Busch and R. A. Dodd (ISD, EMD)

Anelastic Measurements of Atomic Mobility in Body-Centered Cubic Li-Mg Solid Solution, by D. P. Seraphim (IMD)

A Study of Grain Shape in Cemented Titanium Carbides, by Thomas J. Whalen and Michael Humenik, Jr. (IMD)

The Observation of Fatigue Processes in MgO Single Crystals, by I. Cornet and A. E. Gorum (IMD)

Observations on the Thermal Etching of Silicon Iron, by D. S. Hutton and W. C. Leslie (IMD)

The Composition Range of Ti_2Co, by G. R. Purdy and J. Gordon Parr (IMD)

The Effect of Zirconium on the Properties of Extruded Magnesium-Rare Earth Metal Alloys, by J. F. Pashak and T. E. Leontis (IMD)

Deformation Mechanisms and Work-Hardening in Rhenium, by A. T. Churchman (IMD)

Carbide Precipitation and Evolution and Depletion of Matrix in Heat-Resisting Steels and Alloys Treated in Carburizing Atmospheres, by G. Pomey (IMD)

Grain Boundary Grooving by Volume Diffusion, by W. W. Mullins (IMD)

Preliminary Internal Friction Measurements in Chromium, by M. E. de Morton (IMD)

Further Studies of GPI Zone Formation in Al-2 at. pct Cu, by C. Chiou, H. Herman and M. E. Fine (IMD)

The Mechanism of Beneficial Effects of Boron and Zirconium on Creep Properties of a Complex Heat-Resistant Alloy, by R. F. Decker and J. W. Freeman (IMD)

Factors Affecting the Rate of Deposition of Metals in Thermal Dissociation Processes, by George H. Kesler (EMD)

Effect of Solute Impurities on Preferred Orientation in Annealed High Purity Lead, by J. W. Rutter and K. T. Aust (IMD)

Effects of Carbide Dispersion in Molybdenum Alloys, by W. H. Chang (IMD)

Arc Melting and Fabrication of Tungsten, by S. J. Noesen and J. R. Hughes (EMD-IMD)

Stabilization of Certain Ti_2Ni-Type Phases by Oxygen, by M. V. Nevitt (IMD)

Microstrain in Zinc Single Crystals, by J. M. Roberts and N. Brown (IMD)

Comparative Experiments in Drawing, Rolling and Extruding of Bars Through a Pair of Cylindrical Rolls, by N. H. Polakowski and L. B. Schmitt (IMD)

Magnetic Anisotropy and Magnetostriction of Ordered and Disordered Cobalt-Iron Alloys, by R. C. Hall (IMD)

Self-Diffusion in Tin Single Crystals, by J. D. Meakin and E. Klokholm (IMD)

Permeability and Diffusion of Hydrogen through Palladium, by M. van Swaay and C. E. Birchenall (IMD)

Effects of Radiation-Generated Helium and Tritium on the Properties of Aluminum-Lithium Alloys, by D. W. Lillie (IMD)

ENGINEERS AND SCIENTIFIC PERSONNEL

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- CHEMICAL
- CERAMICS
- MECHANICAL
- PHYSICAL CHEMISTS
- METALLURGISTS

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Chemical Engineer. Process engineering responsibilities relative to the wet chemical production of beryllium hydroxide and beryllium oxide from ore. Interest, background and training in unit operations of thickening, filtering crystallizing, etc., highly desirable. Experience not necessary.

Mechanical or Metallurgical Engineer. Process engineering responsibilities relative to the attritioning and sintering of metal powder. Background and interest in powder metallurgy and/or mechanical design experience with metal powder attritioning equipment desirable. Minimum three years experience.

Mechanical Engineer. Process engineering responsibilities for methods analysis for production machining of complex metal parts from blanks on a large scale. Must be able to set up effective methods from the viewpoint of minimum scrap generation and minimum man-hour requirements. Minimum five years experience.

Metallurgical Engineer. Background in the casting of metals, with training or background in the physical chemistry of non-metallic inclusion formations, dissolved gases in metals and their effect on the casting properties of non-ferrous alloys and properties of sheet obtained from such castings. Three years experience required.

Mechanical Engineer or Metallurgical Engineer. Process engineering responsibilities in rolling of non-ferrous alloys. Should be capable of specifying processing steps for various beryllium copper alloys and to develop optimum processing sequences. Three years experience required.

CENTRAL ENGINEERING

Require five to six mechanical and chemical engineers for new metallurgical and chemical plant equipment design, construction and installation. Experience in plant layout and plant engineering highly desirable, particularly in chemical plant, metallurgical vacuum melting and non-ferrous rolling mill area. Specialty openings in the field of ventilation engineering for air contamination control. Four positions require minimum of three years experience; two positions require no experience.

METALLURGICAL DEVELOPMENT

Metallurgical Engineer. Background in non-metallic inclusions and gases in metals for development work on non-ferrous casting processes. No experience required.

Mechanical or Metallurgical Engineer. Strong background and interest in testing methods and testing methods development to design and evaluate new tests for beryllium, beryllium-copper alloys and other special materials. Three to five years experience required.

Customer Service Metallurgical Engineer. Experienced in failure and application analysis, for service to beryllium-copper and beryllium customers. Must be able to diagnose and analyze material deficiencies in diverse applications. Three years experience required.

ADMINISTRATIVE ASSISTANT

Business administration graduate with engineering training to serve as administrative assistant in a large engineering department. Will be concerned with control of capital equipment expenditures, new plant construction and other administrative responsibilities. Experience desirable but not necessary.

SUBMIT RESUMES IN CONFIDENCE TO: R. Y. Heimsath, Personnel Director
The Brush Beryllium Co., Elmore, Ohio
Phone No. 2-2745

* * * * * * * *

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ENGINEERING AND SCIENTIFIC PERSONNEL NEEDED FOR EXPANDING
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HIGH TEMPERATURE COMPOUNDS
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EVALUATION OF PROPERTIES OF HIGH TEMPERATURE ALLOYS AND COMPOUNDS

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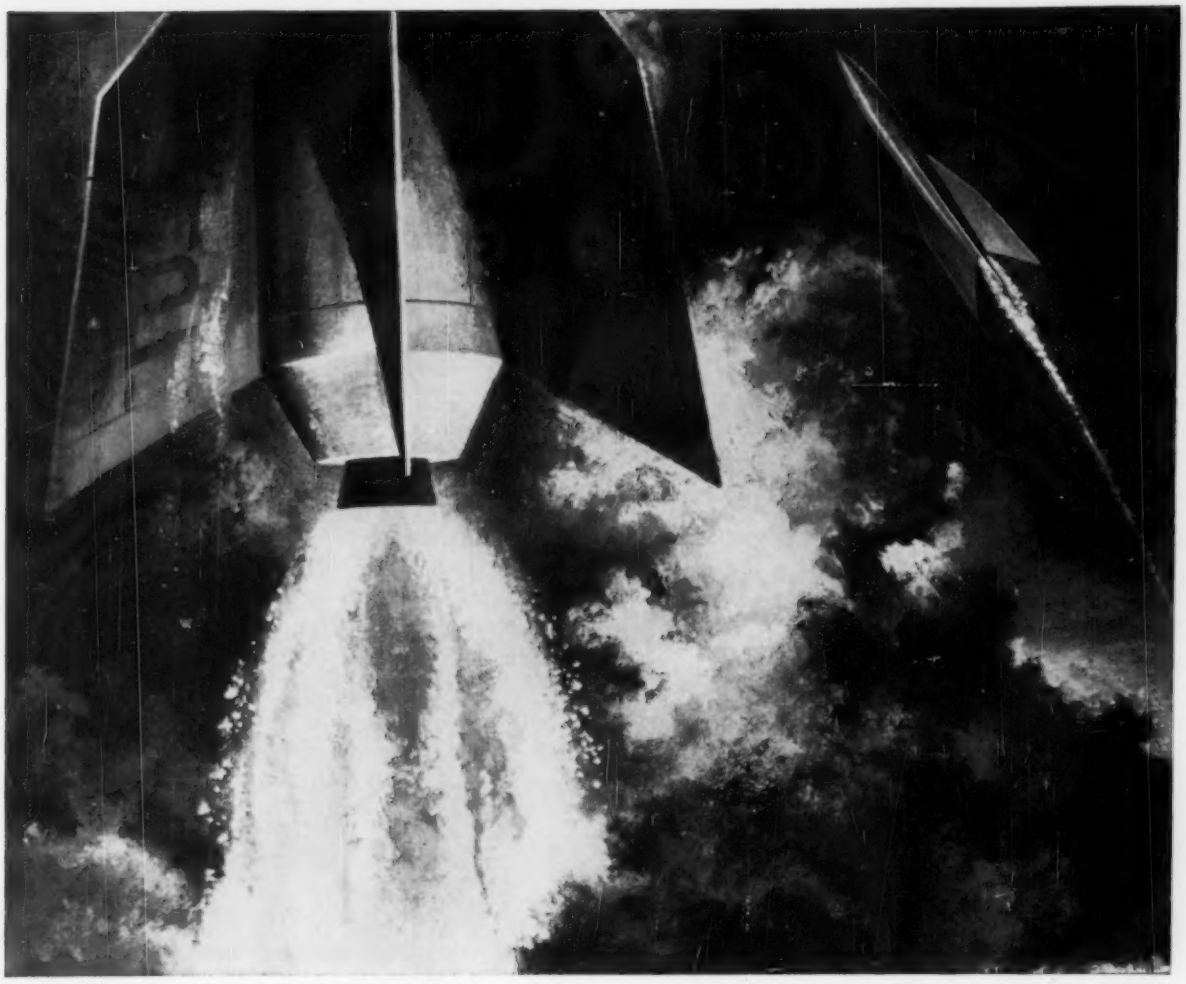

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PITTSBURGH HELD OFF-RECORD

A small-scale Annual Meeting . . . thought we after arriving in Pittsburgh for the Section's annual Off-The-Record meeting to find almost 1000 registrants gathered from the AIME's three constituent societies.

Getting off to a flying start at 9:30 am, the Institute of Metals group heard about Some New Tools for Metallurgical Research. J. C. Swartz of U. S. Steel Corp. described *Internal Friction Measurements*, while F. E. Werner of Westinghouse Electric Corp. told of the ever-widening *Use of Digital Computers in Metallurgical Research*. This was followed by an excellent review of *Ultrasonic Applications* by J. B. Morgan, Allegheny Ludlum Steel Co. These applications in casting, cleaning, grain refinement, and many other areas represent a significant commercial advance as well as a research tool in metallurgy.

Meeting in the shadow of the then cold steelmaking furnaces, the morning and afternoon sessions sponsored by the co-operating Pittsburgh section, National Open Hearth Steel Committee drew "world series" attendance. But time and location were not the only factors behind the record attendance. The program's high level of interest was evidenced by the extensive discussions which followed the presentation of each paper.

The morning NOHC session started off with *Firing Open-Hearth Furnaces With Multiple Mobile Burners Through the Roof*, by Andre Labat-Camy of the Societe Technique d'Exploitation de Chauffage in Paris. He described the installation of five mobile roof burners on each end of a 45-metric ton open-hearth furnace operating on a cold charge at the Gueugnon plant in France. Operating results were so successful that an installation was made of 16 mobile burners on a 75-ton furnace at another plant. This furnace is only now running its first campaign, and the JOURNAL OF METALS expects to be able to report on these results and describe this technique in the April issue. Mobile roof burner units, based on the Labat-Camy design, were reported to be under construction at two plants in Germany, with inquiries from a number of other countries.

Other papers at the NOHC sessions considered the problems of basic roofs, desulfurization of hot metal, increased open-hearth output, and the LD basic-oxygen process.

Several papers in the morning and afternoon sessions of the Mineral Industry group were of interest to metallurgists. One—*Continuous Coking of Coal*, by Edward J. Wasp of Consolidation Coal Co.—was an excellent review covering foreign and US development in this field. He described a 100-tpd traveling hain-grate plant built at Bethlehem for experimental purposes, and went on to tell of work being done by Consolidation Coal making use of the low-temperature fluidized carbonization process. The *char* thus produced is either agglomerated or briquetted and then calcined.

Closing out the day was a bang-up Fellowship Dinner at which R. M. Barnhart served as Toastmaster. Award presentations dominated the Dinner, with J. H. (Jim) Henderson, Pittsburgh section Chairman, being presented a plaque for the Section's participation in Pittsburgh's Bicentennial Year celebration. H. S. Turner, Jones & Laughlin, made the presentation on behalf of the Bicentennial Committee. Jim Henderson was next to take his hand at presentations, bestowing the Section's Best Undergraduate Paper Award on Edward Fortner of Carnegie Institute of Technology. The Leo F. Reinartz Scholarship Award sponsored by the NOHC was next presented to T. H. McGough of Carnegie Tech. Final presentation of the evening was the Pittsburgh NOHC section's F. L. Toy Award for the "best original contribution by a representative of Pittsburgh district plants . . ." The award went to E. J. Hohman, Jones & Laughlin, for his paper on the *Reliability of the Bath Immersion Thermocouple*.

Compliments are certainly in order to all those responsible for such an interesting day of varied meetings.

H. R. Hanley Toasted At 85th Birthday Fete

Herbert R. Hanley, professor emeritus, Missouri School of Mines and Metallurgy, was recently toasted by foreign and American metallurgists alike on the occasion of his 85th birthday. Among the well-wishers was former President Herbert H. Hoover, himself an octogenarian, as well as a former mining and metallurgical engineer.

Dr. George K. Williams, Consolidated Zinc Corp., Ltd., Melbourne, Australia, extended greetings from the metallurgical industry. Dr. Curtis L. Wilson, Dean of the Missouri School of Mines, next voiced greetings from the school and state.

One of the highlights of Mr. Hanley's illustrious career has been his establishment of a department of metallurgical engineering at Cheng Kung University in Formosa. A tape recording of conglatulatory messages from friends there was part of the program. Dr. Walter E. Remmers, a former student of Mr. Hanley's, expressed the sentiments of the many metallurgical engineers he helped produce.

2 scientists

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Revolution in Steelmaking

Hardly more than 10 years old in its industrial application, basic oxygen steelmaking is estimated to have accounted for more than 10 million tons of steel ingots during 1959. LD is expanding at the most rapid rate, with present capacity estimated at 14 million tons. By the end of 1960 some 60 vessels . . . ranging in capacity up to 160 tons . . . are expected to be in operation. Future prospects are bright with many steelmaking firms considering installation. Economics of the process, already interesting, can be phenominal in larger capacity vessels, such as the 300-tonners now being considered by two major steel firms. FWS.

Growth of World Oxygen Steelmaking Capacity*

Country	Firm and Location	No. Vessels	Capacity, Metric Tons	Annual Capacity, Metric Tons: At Present	In 1960	After 1960
LD Process						
Austria	Alpine-Montan Gesellschaft (Donawitz)	2	25	400,000		
		3	30	850,000		
	VOEST (Linz)	2	50	300,000		
		1	50			150,000
W. Germany	Gusstahlwerk Bochumer Verein (Bochum)	2	35	384,000		
	Hoesch-Westfallenhütte (Dortmund)	2 (under construction)				not known
	Eisenwerk-Gesellschaft Maximillianshütte (Sulzbach-Rosenberg)	5 (20 ton converters to be adapted to LD)				not known
	Hüttenwerk Salzgitter (Watenstedt-Salzgitter)	(LD plant under construction)				not known
	Gusstahlwerk Witten (Witten)	1	20	150,000		
France	Sté Dunkerquoise de Sidérurgie (Dunkirk)	2	125			500,000
	Aciéries de Pompey (Pompey)	1	18			
Italy	Dalmine (Apuania)	2	60			400,000
	Fiat (Vado Ligure)	2	60			680,000
Netherlands	Koninklijke Nederlandsche Hoogovens en Staalfabriken (Ijmuiden)	2	60	300,000		
Belgium	S.A. Cockerill-Ougrée (Liège)	1	50		not known	
United Kingdom	Colvilles Ltd. (Ravenscraig)	Planned for 1960 or after. Details not known.				
	Richard Thomas & Baldwins (Newport)	Planned for 1960 or after. Details not known.				
Spain	Altos Hornos de Vizcaya (Bilbao)	2	40		234,000	
Portugal	Siderurgica Nacional (Lisbon)	2	33			not known
Finland	Osakeyhtio Vuoksenniska Aktelbolag (Imatranskosi)	2	20			not known
Poland	Warsaw Special Steel Works (Warsaw)	1 Planned for 1960 or after. Details not known.				
India	Hindustan Steel Ltd. (Rourkela)	3	40		760,000	
	Mysore Iron and Steel Co. (Bhadravati)	2	10			100,000
United States	Acme Steel Co. (Riverdale, Ill.)	2	50	550,000		
	Jones & Laughlin Steel Corp. (Aliquippa, Pa.)	2	65	700,000		
	(Cleveland, Ohio)	2	160			1,000,000
	Kaiser Steel Corp. (Fontana, Calif.)	3	65	1,000,000		
		3	35	500,000		
	McLouth Steel Corp. (Trenton, Mich.)	2	80	925,000		
		1	100			not known
	Phoenix Steel Corp. (Burlington, N.J.)	Details not known.				
Canada	Algoma Steel Corp. (Sault St. Marie, Ont.)	2	66	365,000		
	Dominion Foundries & Steel Ltd. (Hamilton, Ont.)	2	44	644,000		
		1	66			
Japan	Yawata Iron & Steel Co. (Yawata)	2	50	750,000		
		2	60		not known	
		1	60			not known
	Tokai Iron & Steel Co. (Wakamatsu)	2 Planned for 1960 or after. Details not known.				
	(Nagoya)	2	60			not known
	Sumitomo Metal Industries (Kokura)	2 Planned for 1960 or after. Details not known.				
	Nippon Kokan K.K. (Kawasaki)	2	42	750,000		
	(Mizue)	2	60		not known	
	Nakayama Steel Works Ltd. (Funamachi)	1 Planned for 1960 or after. Details not known.				
	Kobe Steel Works Ltd. (Kobe)	2	50			not known
	Fuji Iron & Steel Co. Ltd. (Muroran)	3	60			not known
	(Hirohata)	2	50			not known
		1	60			not known
	Amagasaki Steel Works Ltd. (Amagasaki)	2	30			380,000
Brazil	Usina Siderurgica de Minas Gerais (Ipatinga)	2	50			500,000
	Cia. Sia. Belgo Mineira (Monlevade)	2	30	150,000		
		1 not known				
U.S.S.R.	W. Siberian Iron & Steel Works (Stalinsk)	not known				
	Petrovsky Steelworks (Dnepropetrovsk)	3	22	not known		
	Stalinsk Steelworks (Kuznetsk)	not known	80	not known		
	Krivoi Rog Steelworks (Krivoi Rog)	2	40	not known		
Kal-Do Process						
Sweden	Domnarfvetsjernverk (Domnarfvet)	2	27	195,000		
		2	35			not known
	Oxelosund Jernverk (Oxelosund)	2	100			453,000
France	Sté Lorraine de Laminage Continu (Seremange)	2	50			700,000
Rotor Process						
Germany	Hüttenwerk Oberhausen (Oberhausen)	1	60			
		1	100	480,000		
	Hüttenwerk Ilsede Peine (Ilsede Peine)	1	65	not known		
United Kingdom	Richard Thomas & Baldwins (Redbourn)	Planned for 1960 or after. Details not known.				
South Africa	South African Iron & Steel Industrial Corp. (Vanderbijl Park)	2	89			980,000

* Prepared from reports of the British Iron & Steel Federation, Intelligence Dept. and JOURNAL OF METALS files.

FALL MEETING

BEST YET

THE gathering point of the railroads was also the gathering point for metallurgists during the first week of November. Metallurgists from all over this Country and many foreign lands descended upon Chicago for the Fall Meeting of The Metallurgical Society, held in conjunction with the American Society for Metals' National Metal Congress and Exposition.

A total of 214 technical papers were presented—the majority from the Institute of Metals Division—but with participation by all three Divisions of the Society. All sessions were well attended, with *Standing-Room-Only* signs displayed at many. Good weather and the strike-bound steel industry combined to send total registration to almost 1400.

Steel and refractory metals

The Iron and Steel Div. sponsored two sessions: one on steelmaking techniques, and the other on developments in casting. The first featured papers on the Strategic-Udy process . . . automation in the sinter plant . . . use of natural gas and coke-oven gas in the blast furnace . . . and recent LD developments. Vacuum casting and continuous casting captured the interest of the afternoon session.

One of the most talked-about sessions at the meeting was the IMD Titanium Committee's symposium, Titanium vs Steel. Airframes, jet engines, pressure bottles, solid fuel motor cases, and marine and chemical plants were considered. Complete coverage of the Symposium will appear in the February issue of JOURNAL OF METALS.

On Monday, the first day of sessions, the IMD Refractory Metals Committee teamed up with the EMD's High Temperature Materials Committee to sponsor a symposium on Preparation, Purification, and Properties of Refractory Metals. Molybdenum, tantalum, columbium, and tungsten received special attention at the symposium. In addition, reports were presented on electron beam melting and consumable arc melting.

Metal processing session

Monday was also the occasion for an IMD-sponsored session on Metal Processing. Altogether nine papers were presented, six dealing with the melting or casting of ingots, one on metal working, another on evaluation of drawability in steel sheets, and still another describing a method for producing large sections from metal powders.

Progressive Solidification Study for Vacuum Cold Hearth Melting, by J. H. Kelley, G. Facaros, and B. W. Swanson, Westinghouse Electric Corp., reported studies which have enabled them to melt up to 86 lb per min in a 12-in. vacuum arc furnace, as compared to the usual rate of 11 lb per min. Although the cooling rate is not easily controlled, one can vary several factors which relate to heat input. Data on furnace heats from six different sized ingots were correlated with mathematical analysis and analog simulation. The best properties in the ingots were realized when the pool depth of the molten metal was less than the diameter of the ingot.

Distribution coefficients for several elements in dilute binary and polynary magnesium alloys were discussed by A. S. Yue and J. B. Clark, Dow Chemical Co., in their paper *Directional Freezing of Magnesium Alloys*. Equilibrium conditions are closely approached at low freezing rates, as indicated by the small variation in distribution coefficient with freezing rate. When the freezing rate is low, and the concentration of solute does not exceed the maximum solid solubility for the system, solidus data may be calculated from data obtained from directional freezing technique. This is especially useful in systems which exhibit very limited solid solubility.

Vacuum melting Zircalloy increases the pool depth and makes for more uniform composition, according to J. H. Hart, Westinghouse Electric Corp. Double melting is necessary to bring down the gas content, particularly the hydrogen, but no significant change was noted in mechanical properties except for those changes explainable on the basis of gas content. A higher melting rate and lower power consumption favor vacuum melting over melting in an inert atmosphere.

A theoretical analysis of the effect of ultrasonic irradiation during the freezing of metals was presented by W. A. Tiller, D. H. Lane, and J. W. Cunningham, Westinghouse Electric Corp. The theory predicts that ultrasonic energy, properly applied, should yield structures comparable to those obtained from low superheats even though the super-

heat may be quite high. This would be useful in producing fine, equiaxed grains in castings ingots made by the consumable electrode method in watercooled molds. Several normally non-forgeable materials were rendered forgeable by this technique.

Methods for vibrating melts during solidification were reviewed by Bianchi, Kelley, and Carnahan, of Westinghouse Electric Corp., in *Use of Vibration in the Solidification of High Temperature Alloys for Refractory Metal*. Power requirements vary from about 2 w per lb for a 60 cycle source down to as low as 0.05 w per lb for impulses as low as one impact every 10 sec. Work now in progress may reduce this to 0.002 w. During the question period, it was stated that vibration of 10 effects a reduction of pipe. The effect of amplitude shows fair correlation at higher frequencies, but not at impulse levels.

Vibration during the making of ingots by vacuum arc melting refines the grain, according to another paper by D. R. Carnahan and L. M. Bianchi. *A Study of Melting Procedures as Related to Ingot Solidification* reports on making 12-in. diam ingots of rotor steel and shows that different grain structures may result from using different furnaces, even though an effort is made to employ identical procedures.

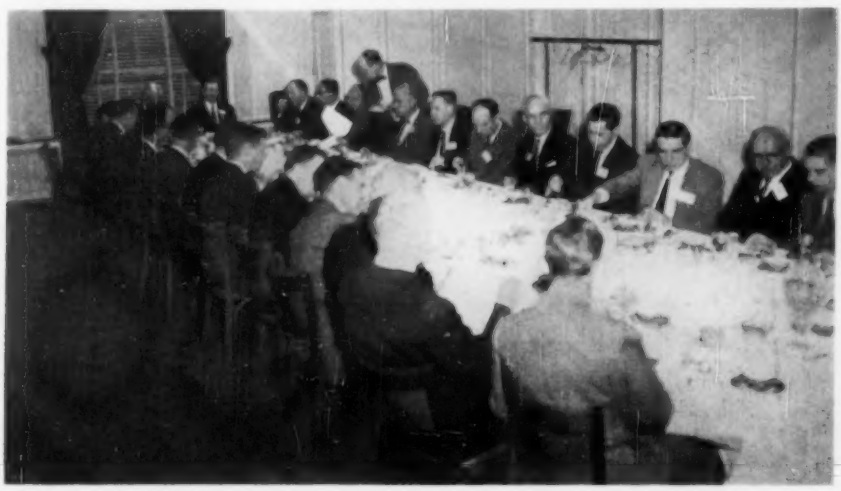
S. Floreen, D. V. Ragone, E. E. Hucke, and W. Steurer of the University of Michigan reported a detailed study of the forces at work and the changes in mechanical properties which resulted from spinning cones of aluminum and cartridge brass. *An Investigation of Metal Spinning* notes that, although the properties were about what might be predicted from a consideration of similar reductions by rolling, the use of a computer in analyzing the data permitted the investigators to supplement the direct observations with quantitative treatment from a theoretical standpoint.

In the range of thickness from 0.009 to 0.065 in. the bulge test gives reproducible results on the drawability of steel sheet, according to E. S. Madrzyk, W. N. Lambert, and F. E. Gibson in *A New Method of Determining the Drawing Quality of a Sheet by Use of the Hydraulic Bulge Tester*. The method the Inland Steel Co. engineers developed uses as a criterion the amount of bulge that can develop across a 10-in. diam opening before plastic flow continues without a corresponding increase in hydraulic pressure.

The compaction of metal powder into continuous bars was described by Charles Deibel and Frank Emley, Westinghouse Electric Corp., in *A New Method for Compacting Metal Powders Into Continuous Sections*. Bars 2 in. wide, 1 in. thick, and 6 ft long have been made from several kinds of powder. These have been further reduced to electrodes, sheet, and tape. The method employs a cyclic compaction in a moving die. Alloys, as well as composite materials, have been prepared. The method offers high yield, versatility, and low operating costs.

Other IMD sessions

A two-part session on the Effects of Irradiation on Fuel and Fuel Elements was presented on Wednesday, Nov. 4th. The first part took up the behavior of metallic fuel materials, discussing the fundamentals of fission damage and explaining such destructive phenomena as growth swelling, and radiation-induced phase transformations. Following



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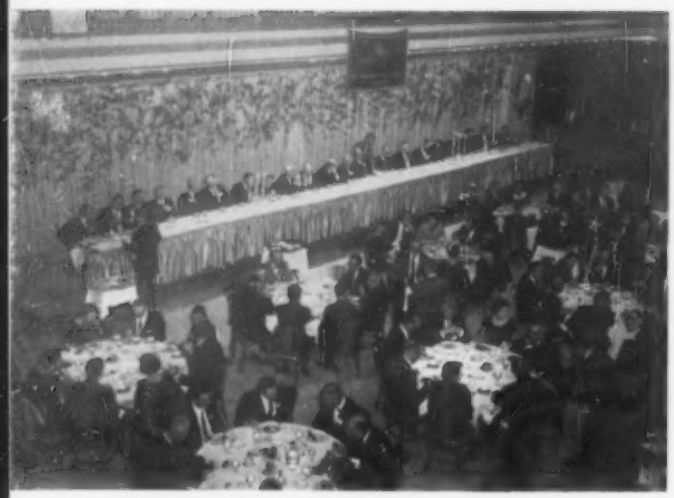


Annual Fall Dinner

ASM Past-President, C. H. Lorig, addresses Fall Dinner. Shown seated are (l to r) Metallurgical Society President, John Chipman, and speaker, Dean William L. Everitt.

Below . . . Pausing before the banquet (l to r) are AIME Secretary, Ernest Kirkendall; AIME President, Howard C. Pyle; and Metallurgical Society Treasurer, T. D. Jones.

this came papers on the irradiation behavior of engineering materials. The symposia were sponsored by the IMD Nuclear Metallurgy Committee.

That day also witnessed an abstract session on Refractory Metals. A total of 12 papers were presented—six relating to tungsten, three to columbium, and one to molybdenum, thus indicating the current emphasis in these refractory metals. Three papers dealt with the mechanical behavior of unalloyed tungsten as a function of temperature. The effects of impurities on the properties (both substitutional and interstitial) were discussed. In a paper on the consolidation of tungsten by pressing, it was concluded that practically all technical pressing rates (designated as quenched pressing) are too fast and prevent natural relaxation processes from taking place. The slip casting process for tungsten was described in another paper. A method for the determination of latent heats of impurities, which undergo phase transformations during sintering, was also described.

The three papers on columbium related to the mechanical behavior of the unalloyed metal and columbium-base alloys. A maximum in fatigue properties was observed for commercially pure columbium. The strengthening of columbium alloys was analyzed in terms of atomic misfit and the valency of the solute. Another paper presented the properties of two columbium-base alloys.

The paper on molybdenum related the effect of prestrain and polygonization on the creep resistance of molybdenum. Molybdenum which was prestrained sufficiently exhibited the greatest creep resistance. The thermoelectric properties of molybdenum with rhenium, and tungsten with rhenium, and their practical applications for thermocouples were also discussed. The IMD Refractory Metals Committee sponsored the symposium.

Melting and Casting

On Thursday, the final day of the meeting, the IMD Nonferrous Metallurgy Committee presented a two-session exploration of Current Practices in the Melting and Casting of Nonferrous Metals. Three papers were presented in the morning session. *Melting and Casting of Zinc at Trail, B.C.*, was a summary of operating experience with their induction furnaces and casting machine, first described in the September 1957 issue of JOURNAL OF METALS, when still in the installation stage. Author of the paper was J. M. Buchanan, Consolidated Mining and Smelting Co. of Canada, Ltd. The development of alloying techniques was described and a description given of the installation of additional induction melting furnaces.

In *Current Practices in the Melting and Casting of Copper Alloys*, P. H. Kirby, American Brass Co., emphasized the economic role played in the use of metallurgical equipment, even at the sacrifice of metallurgical efficiency. Considerable discussion indicated the audience's great interest in the subject.

Research on the influence of alloying elements and impurities on the hot and cold working characteristics of nickel alloys was reported in *Melting and Casting of Nickel Alloys*, by C. G. Bieber and R. A. Decker, International Nickel Co. These effects were presented as comprehensive groupings of elements with similar effects. Discussion of the paper indicated that this information was new to the audience and of great interest.

An additional six papers were presented in the

afternoon, including two papers on aluminum. *Gas and its Control in the Casting of Aluminum*, by D. L. LaVelle, American Smelting & Refining Co., discussed a number of important factors in the techniques for smelting and fluxing aluminum alloys. The determination of hydrogen gas content was reviewed, including discussion of the vacuum gas test. In addition, methods of reducing hydrogen content were described in accordance with recognized techniques, while the effect of vacuum level on the gas test was reviewed during the discussion period. Combinations of inert gases with chlorine were also described as being useful in removing hydrogen gas from molten aluminum alloys.

Factors Affecting the Structure of Continuously Cast Slabs of Aluminum, by Dieter Altenpohl Aluminum Foils, Inc., was the second paper. He presented theoretical, experimental, and production data and experience to assist in the understanding and definition of mechanisms of hydrogen gas introduction and removal from aluminum alloys. The paper also described the casting of high-purity slabs for further fabrication. Detailed discussion of cast structures was also presented.

Annual fall dinner

Tuesday evening marked The Metallurgical Society's Annual Fall Dinner. Presiding over the banquet was Harry J. Jackson, Battelle Memorial Institute, filling in for the scheduled master of ceremonies T. A. Read, who was unable to attend because of illness. Mr. Jackson did an admirable job —particularly on such short notice—and definitely earned the sobriquet, *genial toastmaster of the evening* . . . C. J. Hunter, Chairman of the Chicago Section, AIME, welcomed members to Chicago. Following, came well wishes on the success of the meeting by AIME President Howard Pyle.

John Chipman, President of The Metallurgical Society, congratulated the Institute of Metals Division on its continuing sponsorship of the Fall Meeting, held annually in cooperation with the American Society for Metal's Metal Congress. Representing ASM were C. H. Lorig, last year's President and a long-time AIME member, and Alan Ray Putnam, ASM's new Executive Secretary, who was making his first appearance at an AIME function.

Speaker of the evening was William L. Everitt, Dean of the University of Illinois' College of Engineering, and current President of the Engineers Council for professional Development (ECPD). His topic was *Engineering Education in Russia*. But Dean Everitt did not limit himself to the subject—entertaining the crowd with a humorous account of his entire trip through the Soviet Union.

With the ringing down of the curtain on what is now last year's Fall Meeting, we can look forward to even bigger and better things at this year's meeting, already in planning for the Sheraton Hotel in Philadelphia. It will be coming up sooner than you think, too, for this year's meeting will be Oct. 16-21.

Before closing out the chapter on the 1959 Fall Meeting JOURNAL OF METALS wishes to thank the following people for their kind help in reviewing certain technical sessions at the meeting:

W. T. Battis, American Smelting & Refining Co.;
E. V. Blackmun, Aluminum Co. of America;
A. B. Michael, Fansteel Metallurgical Corp.; and
K. E. Rose, University of Kansas.

AT FALL MEETING

Hafnium, Molybdenum Techniques Revealed

PRODUCTION AND PURIFICATION OF HIGH-PURITY HAFNIUM

A paper by D. S. Fairgrieve and J. W. Fortner of Wah Chang Corp.
Reviewed by R. G. Jones of Wah Chang Corp.

THE quality of hafnium metal in commercial production has been improved by a) passing crude hafnium tetrachloride vapor through a fused salt (NaCl-KCl) bath before reduction by the Kroll process and b) melting the metallic sponge into an ingot in an electron beam furnace.

The salt bath purification is run on a batch basis. The crude $HfCl_4$ is heated to a temperature of 275°C in a hydrogen atmosphere to reduce the iron from the ferric to the ferrous state. The vessel is cooled to 180°C and the hydrogen replaced by argon. The temperature is then increased to 350°C to vaporize the $HfCl_4$ and the vapor stream passes through a salt bath consisting of a starting mixture of 20 wt pct fused NaCl-KCl (equal weight mixture) and 80 pct $HfCl_4$. The salt bath has a melting point of 350°C.

After processing 8 to 10 batches of crude $HfCl_4$, the impurity level of the product gradually increases. The temperature of the salt bath is raised to 750°C to remove about 50 pct of the $HfCl_4$ from the bath.

Typical analysis of the products is as follows:

	$HfCl_4$		Salt Bath	
	Crude, ppm	Purified, ppm	Top Layer, ppm	Bottom Layer, ppm
Zr	2.7 pct	2.7 pct		
Al	250	66	570	800
B	9.2	0.2	0.3	5.0
Cr	435	<10	1000	800
Fe	1.5 pct	235	1100	18 pct
Mn	131	<10		
Ni	334	<10	30	600
Si	550	290	750	>1000
Ti	225	47	40	450
Pb	56	15	100	200

After reduction of the $HfCl_4$ by the Kroll process, the hafnium metal sponge is melted into ingot form in an electron beam furnace operating at pressures of 0.01 to 0.03 μ. Under these conditions the oxygen content is lowered to an acceptable level of 100 to 400 ppm. The Brinell hardness of arc-melted sponge is about 200 Bhn; of crystal bar hafnium about 170 Bhn; and electron beam melted sponge is 135 to 170 Bhn. The electron beam melting must be controlled, since the 135 Bhn is too soft to meet the present mechanical specifications. The typical analyses are:

	Arc Melted Sponge, ppm	Electron Beam Melted Sponge, ppm
Zr	2.9 pct	2.9 pct
Al	60	<25
Fe	320	<50
Si	70	70
Ti	20	<10
N	28	27
O	900	400
Bhn	210	170

TIN REDUCTION OF MOLYBDENITE

By A. D. Abraham and Charles Krey, Oregon Metallurgical Corp., and H. Gordon Poole, Colorado School of Mines.
Reviewed by R. G Jones of Wah Chang Corp.

THE problem of scaling-up a laboratory operation for the production of low-carbon, low-oxygen molybdenum metal to semi-pilot plant dimensions has been successfully accomplished. A high-temperature internally-fired molybdenum resistor tube furnace has been designed and fabricated for the desulfurization of high-purity molybdenite with metallic tin, as disclosed by the Nachtman-Poole patents. A gas circulation and purification system has been installed to minimize hydrogen consumption and gather data on hydrogen purification on a pilot-plant scale. The reduction is univariant and temperature dependent. For this reason the rate of reduction can be controlled quite well by controlling the temperature during reduction. The desulfurization can be performed equally well in a vacuum, in a flowing inert gas system, or in a flowing hydrogen system. A flowing hydrogen system has several processing advantages; so, this system has been used throughout the work done at OREMET.

From a thermodynamic standpoint there appear to be only a few promising methods for desulfurizing molybdenite. Silicon forms a refractory silicide and, while attractive from a thermodynamic point of view, is undesirable for this reason. Lead is not desirable for reducing molybdenite because of significant vapor pressure in the reduction temperature range. Hydrogen reduction is unattractive because of the slow rate of reaction. Both tin reduction and thermal dissociation are attractive from a thermodynamic point of view for the desulfurization of molybdenite. Both reactions are univariant and temperature dependent.

In order to obtain a reasonable reaction rate in the tin reduction process an operating temperature between 1250° and 1300°C has been used. An operating temperature between 1600° and 1700°C has been used to produce molybdenum by the thermal dissociation of molybdenite. The fact that hydrogen reduction of molybdenite is not attractive from a rate standpoint was also verified.

The newly-designed molybdenum resistor tube furnace used in the reduction processes at OREMET was described in detail. A flow of hydrogen gas is purified and passed over a heated molybdenum resistor in the upstream end of a ceramic tubular retort. Hydrogen is an excellent heat transfer medium. All of the heat necessary for the reaction and evaporation of sulfur-containing products is carried by the hydrogen to the briquetted charge. The reaction products are entrained in the pure hydrogen gas stream and carried out the downstream end of the tubular retort. The gas then passes through a purification train and is recycled back into the ceramic retort.

The furnace performs well and is amenable to scale-up to both pilot plant and plant scale operations. The resistor heating element has been designed to fit the power requirements of the tin reduction process and contains no welded joints. Since it is not necessary to weld electrical connections, element fabrication and replacement is a relatively simple operation. Another unique feature of the furnace is the close resemblance to a laboratory-scale furnace operation in that an experimental charge may be removed or reinserted into the reaction zone in a matter of minutes. For this reason rate data can be gathered quite easily on a variety of reactions.

The metal produced by the tin reduction of molybdenite is thus far of comparable purity to the low-oxygen, low-carbon molybdenum produced by the thermal dissociation of molybdenite in vacuum by the Climax Molybdenum Co. of Michigan. The carbon content of the OREMET-produced metal appears to be less than the metal produced by the thermal dissociation of molybdenite in vacuum equipment. It was also noted that OREMET has been using the Kjeldahl method for nitrogen analysis and other laboratories have been using vacuum fusion methods.

The former method almost invariably gives higher nitrogen values. The question of the accuracy of the commonly used nitrogen analysis methods was raised. From observations and data on hand it appears quite possible that the actual nitrogen content in high-purity molybdenum may be higher than indicated by vacuum fusion analyses. The OREMET laboratories have not as yet verified the applicability of the Kjeldahl method in very low nitrogen ranges on molybdenum. If this is true, some of the anomalies associated with molybdenum may be compatible with this situation.

This entire project was sponsored by the Naval Bureau of Ordnance.

Received too late for inclusion in this issue are reviews of the papers. *Tantalum Metal by Selective Solution* and *Molybdenum by Direct Thermal Dissociation of Molybdenum Disulfide*. These will be printed in the February issue of JOURNAL OF METALS.

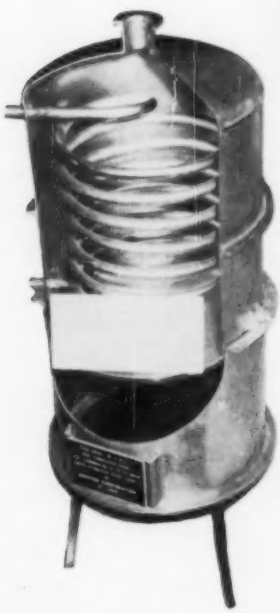
EXPOSITION OF CHEM INDUSTRIES

New Metals Made a Strong Showing At This Year's Exposition of the Chemical Industries

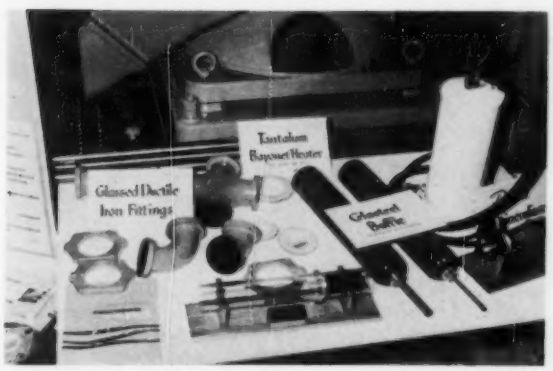
More than 500 exhibitors crowded into the New York Coliseum early in December to show a bewildering variety of pumps, valves, computers, and other equipment of interest to the chemical process industries. Pictured here are some of the new metals that were on display.

Zirconium, titanium, stainless, and Inconel piping at Ladish Co.'s exhibit.

Columbium, tantalum, and vanadium tubing, shown by Superior Tube.



Welded reactor fabricated from titanium by the Nooter Corp.



Ductile iron and tantalum equipment shown by Pfaudler Permutit Inc. Their exhibit also featured a zirconium-lined reactor.

A New Method of MATTE REFINING

. . . by pressure leaching and hydrogen reduction.

Experimental work by Sherritt Gordon has led to the development of techniques for pressure leaching and recovery of high-purity metals from mixed mattes of nickel, copper, cobalt, and iron.

by R. F. Pearce, J. P. Warner, and V. N. Mackiw

THE combination of hydrometallurgy and pyrometallurgy in the refining of metals from ores has been in use for many years; flotation followed by smelting, leaching followed by smelting, and roasting followed by leaching, are examples which readily come to mind. In other cases smelting may occupy a middle position, for instance where a flotation concentrate is smelted to produce anodes for electrolytic refining.

The extension of the limits of practical hydrometallurgy to include operations at above normal temperatures and pressures has widened the field of application of this treatment method. And pressure leaching, with or without pressure reduction of metals, is now in use[1-6] or planned[8] for several metals under a variety of conditions. These applications use pressure methods to treat flotation concentrates or the original ore.

Development work by Sherritt Gordon Mines Ltd. has extended the use of pressure leaching to enriched products produced by pyrometallurgy, notably mattes, but including other products as well. This work, which was commenced in 1949 with the successful leaching of a nickel-copper-cobalt matte, has been carried on as occasion demanded since that time. This development appears to have special application to mixed mattes containing several metals, such as nickel, copper, cobalt, and iron. An economic study of the application of autoclave pressure leaching to nickel-cobalt mattes has been published in the Soviet Union.[15] This account appears to be based, at least in part, on data published in North America; it concludes that these processes are economically attractive and recommends further study.

R. F. PEARCE, J. P. WARNER, and V. N. MACKIW are with the Research and Development Div. of Sherritt Gordon Mines, Ltd., Fort Saskatchewan, Alberta, Canada. This is a summary of a paper originally presented at the 1959 AIME Annual Meeting in San Francisco.

In this, as in other hydrometallurgical processes where the ore, concentrate, or matte is treated to yield the refined metal as one integrated operation, there are three stages. In the first stage the unrefined material is leached so that the valuable metals go into solution while, as far as possible, the impurities in the concentrate are left in the soluble residue. The second stage involves the purification of the solution derived from the liquid-solids separation following the leach step. The final stage involves the recovery of the metals in a high state of purity from the purified solution. In this paper, each of the three stages in hydrometallurgical processing is described and several examples given of the application of these methods to the treatment of mattes.

Background

The essential features of the Sherritt-Gordon processes are now well known, having been described in several papers.[7-14] Leaching to bring the valuable metals into solution is conducted under pressure at elevated temperatures in ammonia[7,8] or acid[11] solutions. After conventional liquid-solid separation,[12] the solutions are treated for the recovery of the contained metals. Copper, if present, is usually recovered as a sulfide from ammoniacal solutions[9] or as a metal by cementation or hydrogen reduction from acid solutions. Nickel is selectively reduced by hydrogen, leaving cobalt in solution;[10, 11] finally, cobalt is recovered, also by hydrogen reduction[11].

When this basic process is applied to the refining of materials other than sulfide flotation concentrate of the Sherritt-Gordon type, certain modifications of the conditions for leaching and copper removal can be made. The flexibility of the process is advantageous in that the leaching conditions can be tailored to suit the particular feed material being

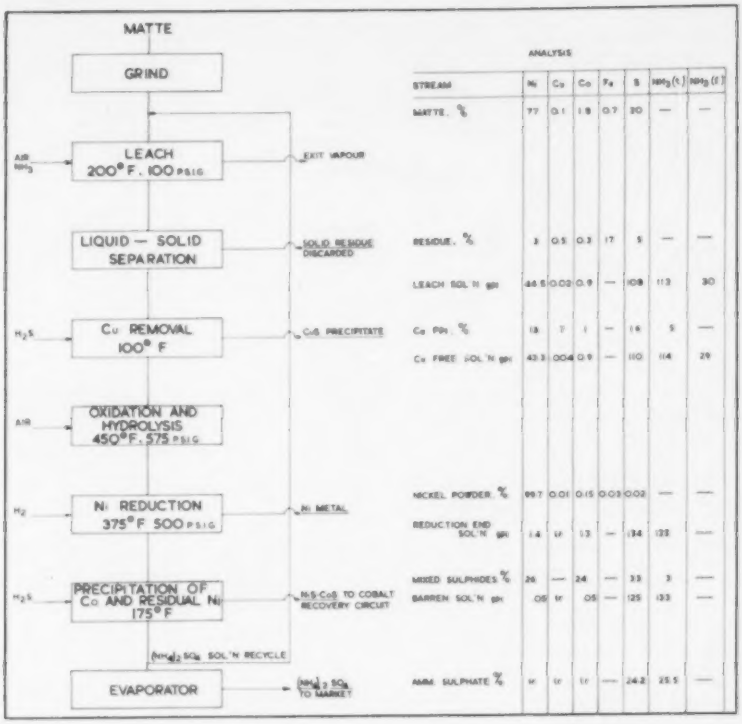


Fig. 1—Ammonia leach and preferential hydrogen reduction for high-grade nickel matte.

treated. Hydrogen reduction of the metal bearing solutions is also subject to some modification, although in general, there is less need to alter the operating conditions proven by four to five years of economical operation.

Matte refining

The application of these processes to the refining of mixed base-metal mattes is governed by several factors.

Basic to any consideration of matte refining are the contents of iron and sulfur. In general, matte will have much less iron and much less sulfur than concentrate for an equivalent weight of nickel, copper, or cobalt. The process of smelting to produce matte rejects a large proportion of the iron and the sulfur associated with it. When producing a matte for refining by these hydrometallurgical processes, the iron content can advantageously be lowered to the minimum consistent with good recovery of base metals in the matte. During leaching, iron must be oxidized, and this requires additional oxygen—in the form of compressed air—above that needed for leaching the valuable metals. Similarly sulfur must be oxidized with air to the sulfate form, eventually to appear as ammonium sulfate. Rejecting excess sulfur during smelting will improve the economics of pressure leaching. The definition of *excess sulfur* will vary from one matte to another, but one of the advantages of these processes is their ability to treat mattes of widely varying sulfur to base metal ratios.

When iron and sulfur contents have been settled by the smelting conditions, the composition of the entire matte is defined for any given raw material. The following factors can then be considered:

a) The selection of either ammonia or acid leaching is influenced by local economic conditions and the analysis of the matte. A substantial cobalt content (over 3 pct Co) in the matte indicates the use of acid leaching, whereas for nickel-copper mattes with low cobalt content, ammonia leaching is preferred.

b) The purification steps, and their sequence, can now be outlined for the other metals present in the matte.

c) The selection of one of the two methods of recovering metallic nickel and cobalt from the purified solutions can be made, the selection being chiefly influenced by the nickel:cobalt ratio in the purified solution. When the cobalt content is low, direct Preferential Reduction of metallic nickel is advantageous. When cobalt content is high, it is preferable to separate the nickel and cobalt by the Soluble Cobaltic Ammine method and to conduct hydrogen reduction on the separate solutions.

Specific examples

The following specific examples of the applications of these processes to actual mattes are based on the result of investigations carried out in the Sherritt Gordon research laboratories and pilot plant at Fort Saskatchewan.

High Nickel Matte

High-nickel matte was selected as being representative of a simple matte. It had the following composition: 77 pct Ni, 0.1 pct Cu, 1.8 pct Co, 0.7 pct Fe, and 20 pct S.

Essentially, this matte consists of nickel sulfide (NiS) and metallic nickel. The iron content is very low, while the sulfur content is about one half that needed to form sulfates of nickel and cobalt. Either sulfuric acid or ammonia leaching can be used, but the ammonia leach is preferred, as the deficiency of sulfur can be made up more economically by circulating ammonium sulfate solution within the process than by the outside supply of sulfuric acid. The purification steps are minor, and the nickel to cobalt

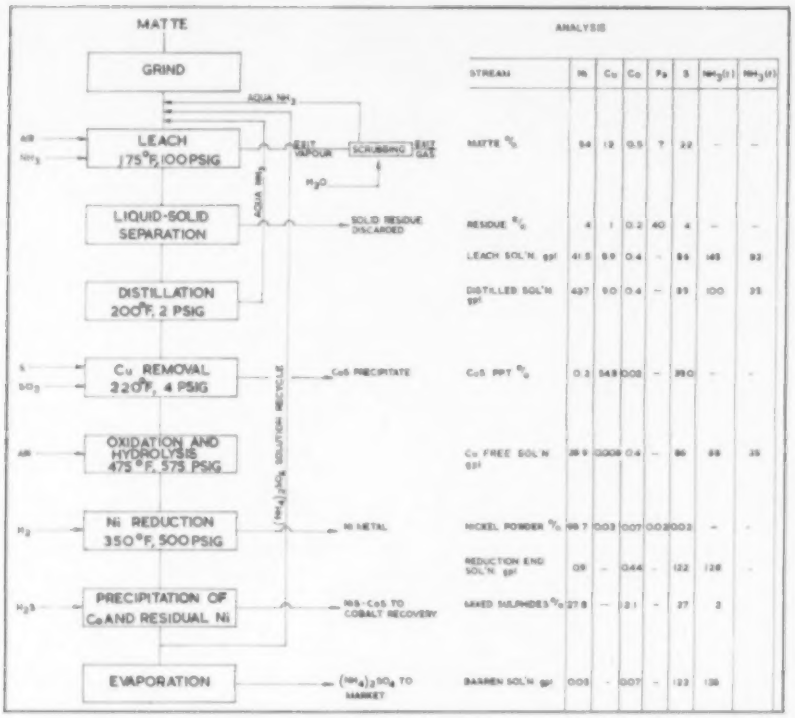


Fig. 2—Ammonia leach and preferential hydrogen reduction for a nickel-copper matte.

ratio is ideal for direct preferential reduction of nickel. A diagrammatic flowsheet is presented in Fig. 1.

Due to the presence of metallics, grinding was conducted to a fineness of 1 pct +65 mesh, which produced 90 pct −200 mesh. With the low iron content, a low ammonia content was furnished in order to leach the metallics. Since the free-ammonia content of the leach solution was low, the temperature could be raised from 175° to 200°F without unduly increasing the vapor pressure of the solution.

These conditions were applied to a pilot-plant investigation of this matte, in which 700 lb of matte was leached daily, in a continuous operation, for six weeks. It was determined that extraction of 97 to 98 pct of the nickel was obtained in 6 to 8 hr and that to increase this extraction to even 99 pct would require much longer leaching time. By filtering and retreating the small amount of residue in a special circuit with return of solution to the primary leach, an overall extraction of 99.8 pct of the nickel was obtained. Extraction of cobalt was 99.2 pct. The solution, after filtering, contained 44.5 gpl Ni, 0.02 gpl Cu, 0.9 gpl Co, 108 gpl S, and 30 gpl free NH_3. Copper was removed from the solution to a content of 0.004 gpl by using hydrogen sulfide; the thionate and sulfamate contents of the solution were destroyed by a combined oxidation-hydrolysis treatment at 475°F, 500 psig, with air. Nickel was recovered by selective hydrogen reduction, while the cobalt left in the reduction and solution was precipitated with hydrogen sulfide. A part of the ammonium sulfate solution remaining was recycled while the surplus was crystallized.

The nickel powder produced showed the following analysis: 99.7 pct Ni, 0.15 pct Co, 0.01 pct Cu, 0.03 pct Fe, and 0.02 pct S.

Nickel-Iron Matte

Matte of the following composition was tested: 29.5 pct Ni, trace Cu, 0.7 pct Co, 58.3 pct Fe, and 7.4 pct S. This matte was included in the series to show the effect of the much increased iron content over the previous example; the low sulfur content indicates that the matte was largely metallics.

The flowsheet selected was very similar to that shown in Fig. 1, using an ammonia, ammonium sulfate leach. A ground product containing 3 pct +65 mesh, 85 −200 mesh was leached in a series of laboratory investigations. All tests were conducted at 20 psig oxygen pressure for 6 hr, with a solution at 7 molar ratio NH_3:Ni. At 175°F, with 200 gpl $(NH_4)_2SO_4$ in the feed solution, nickel extraction was 96 pct, and the cobalt extraction was 74 pct. Increasing the temperature to 200°F improved the extractions to 97 pct and 86 pct respectively. By increasing the ammonium sulfate content to 400 gpl, and 175°F, extraction improved to 98.5 pct for nickel and 90 pct for cobalt. The leach solution contained 42 gpl Ni and 0.9 gpl Co.

Due to the high iron content of this matte leaching proceeded more slowly than for the preceding low-iron matte, and final extractions were slightly lower; the leach residue levelled out at 0.4 to 0.5 pct Ni. The coarse particles of metallics in the leach feed did not appear in the leach residue, showing that such material is leached and broken down if sufficient time is provided. Solution purification and nickel reduction steps were as before.

Nickel-Copper Matte

Matte of the following composition was tested: 54.0 pct Ni, 12.5 pct Cu, 0.5 pct Co, 6.8 pct Fe, and 22.4 pct S.

Matte of this general composition is encountered more frequently than the others in this series, due to the natural association of nickel and copper sulfide minerals in many parts of the world. Usually, a flotation separation may be made to provide a

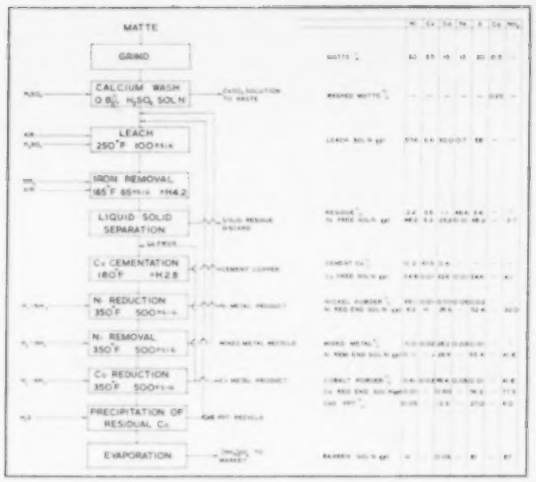


Fig. 3—Acid leach and preferential hydrogen reduction for a nickel-copper-cobalt matte.

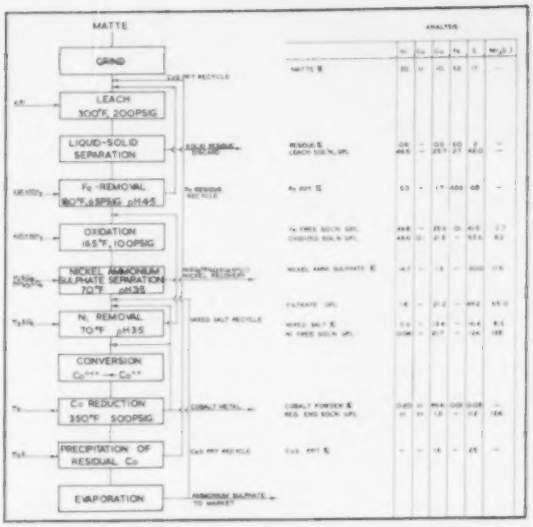


Fig. 4—Acid leach and soluble cobaltic ammine separation for a nickel-cobalt matte high in iron.

copper concentrate low in nickel, and a nickel concentrate that contains some copper. Of several mattes of this type that have been studied, the one with the above analysis has been selected for discussion. The leaching of this matte was investigated in a series of laboratory tests, followed by a systematic study of operating conditions and controls in a continuous pilot plant campaign extending over a three-month period.

The iron content was reasonably low, and the sulfur content about two-thirds that needed to form metal sulfates. The high nickel to cobalt ratio indicated a preference for ammonia leaching, and a significant amount of copper had to be removed from the solutions. Preferential nickel reduction was clearly indicated by the high-nickel and low-cobalt content. Fig. 2 is an outline of the flow diagram.

The laboratory work showed that grinding to pass 100 mesh, with about 70 pct passing 200 mesh gave good extractions, and further showed that finer grinding increased the reaction rate, but tended to make residue filtering slow. The continuous pilot-plant operation demonstrated that the matte was easily ground to 99.5 pct −100 mesh, and that the product was 98 pct −200 mesh; residue filtering did not prove a problem; so, the fine grind was accepted. Due to the presence of an appreciable iron content (6.8 pct Fe), low ammonia to metals ratio leaching could not be applied. If the *free ammonia* content of the leach solution was reduced from 85-90 gpl to 45 gpl, extraction of nickel, cobalt, and copper fell off rapidly. Ammonium sulfate concentration, at 300 to 335 gpl, temperature at 175°F and pressure at 100 psig, were normal. Extractions for nickel of 98.5 pct, for cobalt of 95 pct, and for copper of 98.5 pct were obtained during a two-week demonstration run.

The leach solution was distilled to remove the free ammonia content which was required for leaching, but which was in excess of the requirements for nickel reduction. The ammonia and water vapors were condensed and recycled to the leach feed. Copper was removed from the solution by precipitation as a sulfide, using the sulfur-dioxide-sulfur process developed by Sherritt Gordon. The copper product, at 55 to 60 pct Cu and 35 to 40 pct S, was suitable for smelting in an adjacent smelter.

The final purification for unsaturated sulfur, by high pressure oxidation and hydrolysis was followed by preferential nickel reduction as before. The nickel powder product assayed: 99.8 pct Ni, 0.08 pct Co, 0.04 pct Cu, 0.02 pct Fe, and 0.02 pct S.

Nickel-Cobalt Matte

Tests were made on matte of the following composition: 32 pct Ni, 3.5 pct Cu, 16 pct Co, 13 pct Fe, and 30 pct S.

This matte differed from the preceding mattes, not only in its high cobalt content, but in its high sulfur content; metallics were largely absent, and sufficient sulfur was available to form sulfates of nickel, copper, and cobalt. The high cobalt content of the matte, however, dictated the use of an acid leach, rather than the ammonia-leaching circuits described for the first three mattes.

In the ammonia leach solutions, the limit of solubility of cobalt is less than that of nickel; under the oxidizing conditions of the leach, cobaltic ammines are formed. The pentammine is very soluble, but some cobaltic hexammine sulfate is formed which is substantially insoluble in the solutions. It has been found on high cobalt content materials such as this matte, that when optimum conditions for leaching nickel are applied, the cobalt solubility is exceeded, and the excess cobalt precipitates as a cobaltic hexammine sulfate. This feature prevents the useful application of ammonia leaching to high cobalt mattes. Acid leaching, however, has several advan-

tages for such materials; in particular, the solution strengths may be much higher, thus reducing the volume of solution to be processed.

Shipments of this matte were studied in laboratory tests and also in the continuous pilot plant. The flow diagram is shown in Fig. 3. The laboratory tests showed a calcium content of the matte sufficiently high as to cause trouble with calcium sulfate in solution; a direct leach of the matte produced a solution with 52 gpl Ni, 26 gpl Co, and over 0.7 gpl Ca, with calcium sulfate crystallizing from the solution. A preliminary wash technique was developed, wherein the ground matte was agitated at room temperature and atmospheric pressure with 1 pct sulfuric acid; most of the calcium was dissolved, and the wash solution was removed by filtering. Grinding to 99.5 pct through 65 mesh and 84 pct through 200 mesh was shown to be satisfactory for both calcium washing and leaching of nickel and cobalt. In the leaching step, it was shown that 95 to 100 psig pressure with air was adequate and that 8 to 10 hr leaching time at 250°F gave acceptable extractions; high temperatures allowed shorter leaching times, but did not produce higher final extractions. The most critical variable was found to be the concentration of sulfuric acid in the leach solution; either too little or too much acid caused reduced extraction. The addition of 155 lb of H_2SO_4 per ton of matte (1.37 lb H_2SO_4 per 100 gal leach solution) proved to be the optimum for the pilot plant. Leach solution assayed 57 to 60 gpl Ni, 28 to 30 gpl Co, 6 to 7 gpl Cu, and 0.5 to 1.0 gpl Fe, and extracted 98.5 pct of the nickel in the matte, 98 pct of the cobalt, and 90 pct of the copper. Iron extraction was 3 pct. Since the iron content was low, it was convenient to precipitate it in the leach slurry, before filtering. Iron removal was carried out by the conventional method of oxidation and precipitation, with air for oxidizing and ammonia for precipitation. Operating at 165°F, 5 psig oxygen pressure, and pH 4.1 to 4.3 produced a solution with less than 0.01 gpl Fe; the solid residue was removed by pressure filtration on precoated filters.

Since the solutions were slightly acid (pH 4.2), copper removal was conveniently carried out by cementation on cobalt powder. The copper-free solution at about 55 gpl Ni and 30 gpl Co, was well suited to the Preferential Nickel Reduction treatment. In the first step, nickel was reduced to about 5 gpl, producing specification nickel powder. In the second step, a mixed metal of about 71 pct Ni and 28 Co was reduced, substantially stripping the solution of nickel; this mixed metal powder was recycled to the leach feed. In the third step, the cobalt solutions were reduced to metallic cobalt powder. In each of the three steps, hydrogen is used as the reductant, at 350°F, 500 psig with ammonia addition controlling the extent of each reduction. The following analyses were obtained on the nickel and cobalt products:

	Pct Ni	Pct Co	Pct Cu	Pct Fe	Pct S
Nickel	99.1	0.70	0.01	0.05	0.02
Cobalt	0.4	99.4	0.02	0.05	0.01

Nickel-Cobalt-Iron Matte

Tests were also made on a matte of the following composition: 20 pct Ni, trace Cu, 10 pct Co, 52 pct Fe, and 17 pct S.

This matte was similar to the preceding example, but contained much more iron. It was reported that lower iron contents could not be achieved under the particular local conditions pertaining to this matte. The sulfur content was sufficient to form sulfates of nickel and cobalt. The high cobalt content governed the choice of acid leaching, and no troublesome impurities were encountered. Local conditions directed the use of the Soluble Cobaltic Ammine separating of nickel and cobalt; the flow diagram is outlined in Fig. 4.

Grinding, leaching, and iron removal followed the conditions which have already been discussed. The iron-free solution contained about 45 gpl Ni, 25 gpl Co, and was oxidized with air in the presence of ammonia to transform the cobalt into the cobaltic pentammine form. Nickel was precipitated by the addition of ammonium sulfate and sulfuric acid-nickel ammonium sulfate being sparsely soluble under these conditions. The nickel salt was recovered by filtration for retreatment; it assayed 14 pct Ni and 1.5 pct Co. Residual nickel was stripped from solution by precipitation of a small amount of cobaltous ammonium sulfate, and this precipitate was recycled to the oxidation feed. The cobaltic solution was treated with cobalt powder to convert it to the cobaltous state, and then reduced with hydrogen to produce metallic cobalt; this product assayed: 0.2 pct Ni, 99.6 pct Co, 0.01 pct Fe, and 0.03 pct S.

Conclusion

An extensive program of laboratory and pilot plant investigations has been carried out on the refining of nickel, copper, cobalt mattes by pressure leaching and hydrogen reduction. This program has defined a number of the significant process conditions and has outlined the principles under which a treatment process for a particular matte may be devised. It is believed that these techniques can usefully complement existing refining methods.

References

[1] S. Nashner: Refining at Fort Saskatchewan, *Trans.*, Canadian Institute of Mining and Metallurgy, vol. 58, p. 212.

[2] J. P. Warner: Nickel Recovery at Fort Saskatchewan, *The Industrial Chemist*, Sept. 1956.

[3] G. P. Lutjen: Cobalt at Fredericktown, *Engineering and Mining Journal*, vol. 154, no. 12, p. 72.

[4] J. S. Mitchell: Pressure Leaching and Reduction at the Garfield Refinery, *Mining Engineering*, Nov. 1956, p. 1093.

[5] R. W. Mancantelli and J. R. Woodward: Use of Autoclaves and Flash Heat Exchangers at Beaverlodge, *AIME Trans.*, vol. 202, p. 557.

[6] Forbes Wilson: The Moa Bay-Port Nickel Project, *Mining Engineering*, May 1958, p. 563.

[7] F. A. Forward: Ammonia Pressure Leach Process for Recovering Nickel, Copper and Cobalt from Sherritt Gordon Nickel Sulphide Concentrate, *Trans.*, Canadian Institute of Mining and Metallurgy, vol. 56, p. 363.

[8] F. A. Forward and V. N. Mackiw: Chemistry of the Ammonia Pressure Leach Process, *AIME Trans.*, vol. 203, p. 457.

[9] V. N. Mackiw, R. L. Benoit, R. J. Loree, and N. Yoshida: Simultaneous Distillation of Ammonia and Separation of Copper from Nickel Bearing Solutions, *Chemical Engineering Progress*, March 1958, p. 79.

[10] V. N. Mackiw, W. C. Lin, and W. Kunda: Reduction of Nickel by Hydrogen from Ammoniacal Nickel Sulphate Solutions, *AIME Trans.*, vol. 209, p. 786.

[11] V. N. Mackiw, W. C. Lin, R. L. Benoit, and T. W. Benz: Nickel-Cobalt Separation at Sherritt Gordon Mines Limited, AIME Annual Meeting New York, Feb. 1958.

[12] K. O. Cockburn, R. J. Loree, and J. B. Haworth: The Production and Characteristics of Chemically Precipitated Nickel Powder, *Proceedings*, 13th Annual Meeting, Metal Powder Association, Chicago, 1957.

[13] D. J. I. Evans, W. Kunda, and P. Chiang: Studies on Flocculants for Settling, Thickening and Filtration in the Sherritt Gordon Process, *Can. Journal of Chemical Engineering*, June 1957.

[14] K. O. Cockburn, R. J. Loree, N. C. Updegraff, and D. M. Hess: Production and Use of Tonnage Hydrogen Sulphide at Fort Saskatchewan, *Trans.*, Canadian Institute of Mining and Metallurgy, vol. 60, p. 348.

[15] T. G. Begunova: Economic Review of the Autoclave Processes for Ural and Kolski Peninsula Nickel Plants, *Tsvetnye Metally*, vol. 30, no. 7, p. 14-22, 1957, Moscow.

EVALUATING EXPLOSIVE METAL FORMING

This process, while not a panacea for all metalworking problems, appears to be well established as a compliment to other forming techniques.

by C. P. Williams

DURING the last few years, much has been said, written, and published regarding high-energy-rate deformation of metals and alloys. Many industrial, research, and military organizations have been engaged in investigations of high-strain-rate techniques and devices to assess the possibilities for, and practicability of, forming parts by this novel approach. Today, rewards of the efforts are beginning to materialize in the form of metal parts of acceptable quality and cost, albeit the quantities are now small and the ultimate utility and economy of the various processes evolving is yet to be firmly established.

Explosives as energy sources

Explosives are chemical compositions that, under certain conditions and when properly initiated, decompose rapidly to release high pressure gases and produce shock waves. There are two principal mechanisms of explosive reaction: deflagration and detonation.

Low explosives

Low explosives (e. g., smokeless powder and black powder) are of the deflagrating type and are characterized by rapid buring, as occurs in the breach of a rifle to drive the projectile from the barrel. The burning rate of such materials can be on the order of hundreds of meters per second and is partially dependent upon the degree of confinement. Under proper confinement, pressures in the range of 100,000 to 300,000 psi can be generated by low explosives.

High Explosives

Detonation of high explosives (e. g., dynamite, TNT, RDX, PETN) is characterized by a reaction zone traveling through the explosive at velocities of thousands of meters per second. Because of the high speed of reaction, most detonating explosives release energy at a constant rate, irrespective of confinement. When a high explosive is detonated, a shock front, with a pressure on the order of several million psi, is generated. The amplitude and shape of the pressure pulse behind the schock front can be controlled quite precisely.

The curves in Fig. 1 illustrate schematically the different pressure-time relationships obtainable with low and high explosives. The area under the curves (total energy release) is the same for both. The significant difference between the two is the extremely high rate of energy production characteristic of the high explosive.

Preference for high explosives

Du Pont's preference for high explosives in attempting to form metals was mainly predicated on economics. The necessity for confinement when using low explosives would appear to require relatively elaborate and expensive tooling.

Mechanism of high explosive forming

As suggested earlier, the strong pressure pulse produced when a high explosive is detonated travels into a surrounding medium at thousands of feet per second. The photograph in Fig. 2 shows the initial stages of growth of the shock front and the gas bubble from a sphere of high explosive detonated in water. At this stage of development, the shock front (outer gray ring) is moving at a velocity of approximately 3500 meters per sec and the gas bubble (heavy black ring) is expanding at a velocity of approximately 1000 meters per sec. Therefore, the expansion of gaseous products is seen to be lagging well behind the shock front.

The results of controlled experiments involving the deformation of a circular flat aluminum plate by an explosive charge in a fluid medium, and observed by high-speed photographic equipment, have led us to believe that the high pressure shock wave is the prime mover in high explosive forming.

Mention should be made of the fact that the pulse obtained from a high explosive can be varied

C. P. WILLIAMS is a technical representative of the Explosive Dept., E. I. du Pont de Nemours & Co., Inc., Wilmington, Del. This paper was presented at the Philadelphia Regional Technical Meeting of the American Iron and Steel Institute, November 1959.

from the abrupt, intense pulse usually associated with high explosive, to the broader, much-less-intense pulse characteristic of low explosives. By changing the weight of the explosive, the geometry of the charge, the medium and distance between the explosive and the part to be formed, or the type of explosive employed, a wide variety of shapes and strengths of pressure pulses can be achieved. By proper control of these variables, the most favorable conditions can be obtained for forming any particular metal or shape of part.

Possible applications

Investigations have been undertaken with a number of industrial concerns involving explosive metal forming as a possible solution to existing or potential forming problems. Principal aims in engaging in these activities were 1) to explore the practical aspects of applying the explosive mechanism just described; and 2) to begin an economic appraisal of the merits of the process in relation to other established metal forming techniques.

The basic system used in these investigations consisted of a die, a blank, an appropriate explosive charge properly positioned, and a transfer medium between the charge and the blank. Experience has shown that water is an efficient means for transmitting the shock wave from a detonating explosive. Also, the use of fluid of sufficient depth above the charge effectively muffles the noise generated by the explosion. The fluid also minimizes damage to the surface of the part to be formed by particles emanating from the explosion. If the amount of deformation required is great, and dimensional tolerances of the part are critical, evacuation of the space between the blank and the die was usually necessary. Sealing techniques to exclude entry of foreign matter between the blank and the die were essential in all cases. In addition, hold-down or restricting devices were required in many instances to produce proper flow of the metal into the die cavity.

In passing, reference should be made to a cursory evaluation of the possibilities for free forming (i. e.,

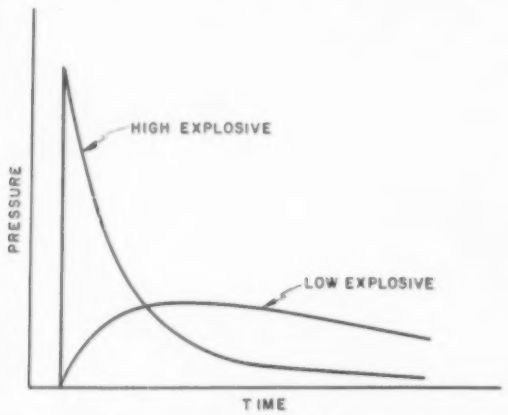


Fig. 1—Typical pressure pulses of high and low explosives.

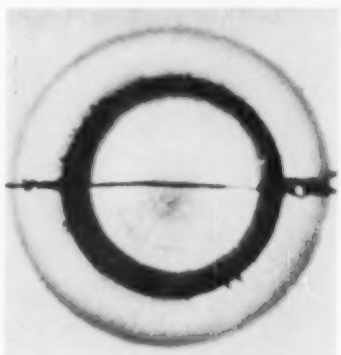


Fig. 2—Shock front and gas bubble from high explosive detonated in water.

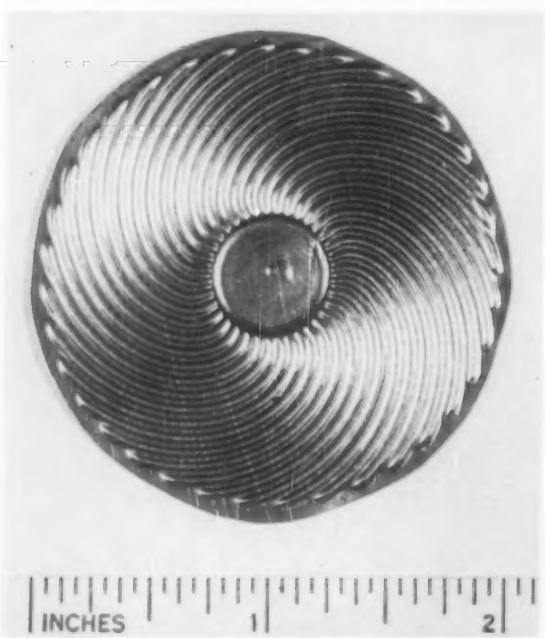


Fig. 3—Explosively formed, 8-ft, mild-steel railroad tank car head.

Fig. 4—Fuel filter disc formed of type 302 stainless.

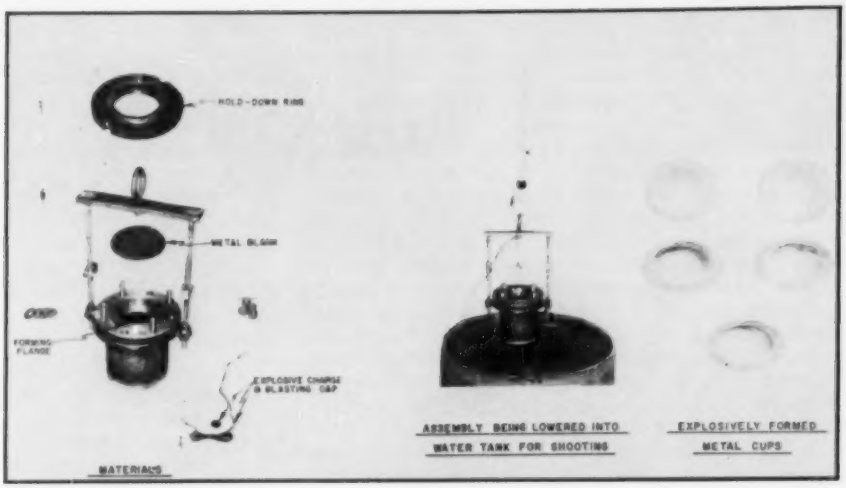


Fig. 5—Cupping test performed on 13 selected ductile metals and alloys.

no die cavity) materials by proper use of explosive geometry and location. This method appears to be applicable, however, only where roughly formed parts are acceptable and tolerances are very liberal.

Dished Heads

Considerable work has been done in forming a variety of sizes and shapes of dished heads. The largest head produced successfully was a railroad tank car end (Fig. 3) 8 ft in diam and 3/16 in. thick. This particular piece was considered to be somewhat difficult to form by existing techniques without wrinkling or excessive thinning, because of the low thickness-to-diameter ratio. In addition, high equipment and tool costs warranted a close look at explosive forming where only a female die would be needed.

The forming of scaled-down heads (1 to 3 ft diam) either by free forming through a ring or into wood dies was attempted first. The information obtained was found to be quite useful in designing for the full-scale test.

The die design finally selected for the full-scale experiment consisted of a mild steel shell, constituting the die cavity, to which concentric mild steel rings were welded for support. A heavier draw ring with liberal draw radius was affixed to the top of the cavity shell, and a clamping ring was attached over the blank to provide adequate restriction of blank movement when accelerated into the cavity. The explosive charge was positioned above the blank and the entire assembly, which weighed approximately 14 tons, was handled by crane for immersion in, and removel from, a shooting pond. On the first attempt, an array of holes allowing air to escape from the die cavity proved to be inadequate. Accordingly, evacuation of the cavity was employed on subsequent shots to remove the effects of air entrapment.

Approximately 95 pct complete forming of the head was found to be possible through the use of a ring charge weighing close to 10 lb. A second and much lighter charge was used to drive the head into intimate contact with the cavity wall. Although the tooling described functioned satisfactorily for the limited number of experiments performed, it was apparent that more robust and hence more costly die construction would be required if this head were to be produced in quantity by this technique.

A much deeper head, approaching a hemisphere in fact, was produced experimentally in miniature as a possible forerunner to forming missile motor-case domes explosively. A steel die was used for this work, and thinning was reported to have been held within tolerable limits on this scale by the use of a generous draw radius.

Cylindrical and conical parts

Many of the parts obtained experimentally were formed from cylindrical or conical blanks enclosed in tooling or appropriate configurations. As can readily be imagined, most of this work was done with tooling in the vertical position. The blank was usually sealed at the bottom, filled with water, and the top left open to the atmosphere.

A corrugated cylinder was formed from 310 stainless steel and A-286 and R-235 alloys. The tooling for this work consisted of a tool steel die split longitudinally. Interesting findings here were 1) the extent to which the external weld bead could be planished; and 2) the high dimensional exactness that had *not* been attained from earlier attempts to form this part hydraulically.

Explosive forming was also used to shape a scale-down rocket motor venturi from 0.050-in. 321 stainless steel. The starting blank in this instance was fabricated by welding two straight-sided truncated cones. This blank, threfore, contained a transverse as well as a longitudinal weld. The welds held satisfactorily during forming, but of even greater interest was the ability to produce a flat flange as an integral part of the one-shot forming operation.

Corrugated flat sections

Another illustration of a possible application for explosive forming is exhibited in Fig. 4. In this experimental effort, deep and sharp spiral grooves were formed in 0.005 in. thick 302 stainless steel in an attempt to produce a fuel filter disc. Localized failures in the epoxy resin and soft aluminum dies used precluded a complete evaluation of explosive forming as a means for producing this part, although formation accuracy seemed somewhat better than could be achieved by static forming means.

Sizing

In the course of the forming investigations described above, it became apparent that springback

could be controlled quite effectively and perhaps to a higher degree than obtainable by other forming systems. Therefore, considerable attention, by du Pont and others, has been devoted to the matter of sizing parts to high dimensional accuracy by the explosive forming technique. A semi-elliptical pressed steel (AMS 6434) missile dome was found to measure approximately 4½ ft in diam. A number of these preformed heads have been sized explosively to a diametral accuracy of ± 0.010 in. and a conformance-to-contour accuracy of ± 0.030 in. These results would tend to confirm that spring-back can be closely controlled, albeit not completely eliminated. In fact, this particular effort highlighted the need for sturdy dies as well as design considerations to compensate for spring-back even under these dynamic loading conditions. The tooling first evaluated, which was predominantly of plastic construction, was capable of delivering only a few parts before gross failure of the tool resulted. Subsequent attempts with cast or wrought steels have indicated that more favorable tool life is obtainable.

Basic investigations

It would seem fitting at this point to inspect one basic exploratory investigation in explosive forming now being performed by our research division. The goals of this program were 1) to devise a system for rating metals and alloys for formability when deformed dynamically by explosively generated pressures; and 2) to determine the effects upon the properties of metals imparted by explosive deformation. As may be deduced from the elements shown in Fig. 5, the test system selected generally consisted of the deformation of relatively thin, circular discs, measuring a few inches in diameter, and bore some resemblance to the well-known Ericksen cupping test, used widely for systematic evaluation of drawing properties under static loading. The major departures in the explosive cupping tests were 1) the forming punch driven at velocities of inches-per-second was replaced by an explosive, plus fluid energy source, that moved metal at velocities of hundreds of meters-per-second; and 2) uniform hold-down presure sufficient only to cause uniform metal flow was applied to the disc blanks.

Thirteen ductile metals and alloys were selected for submission to this test. Seven candidates were basic metals, five were heat-treatable alloys, and two were non-heat-treatable alloys. Care was also exercised in selecting materials to assure that FCC, BCC, and HCP structures were duly represented. All materials were annealed and analyzed for mechanical properties and microstructure before submission to the test.

A mathematical model was first devised to predict the behavior of various metals under static deformation on the basis of mechanical properties. The relative formabilities of the metals selected, as determined from measurement of depths and volumes of cups produced explosively, were then submitted for statistical comparisons. A seemingly valid correlation was found to exist. Therefore, we are inclined to believe now that the formability of metals under high-rate deformation can be predicted from classical stress data.

A representative sampling of all cups produced in the test was examined for changes in mechanical properties and microstructure. It was found that hardness increases, thinning profiles, strength increase, grain deformation, and fatigue strength were generally commensurate with similar static forming. A minor increase in elongation could be attributed to uniformity of loading and reduction of friction due to elimination of the male punch.

Random examination of other explosively-formed parts have tended to confirm the results just stated for the explosive cupping test. These findings should be regarded, nevertheless, as tentative conclusions. Considerably more data, especially at higher rates of strain, would appear necessary before the behavior of metals under explosive deformation is fully understood and documented.

Conclusions

Explosive forming is not a remedy for all forming ills confronting the metalworking industry. Initial exhuberance occasioned by suppositions that unusual metal behavior could be obtained and low cost tooling, as well as ultra-simple procedures, could be used has paled somewhat in the light of intensive efforts to reduce that art to commercial practice. On the other hand, explosive forming does appear to have its place. This is a supplemental role to the other well-established or newly-contrived mechanical, hydraulic, and pneumatic forming processes. Justification for the existence of explosive forming as a supplemental technique seems to reside in the following advantages of the process:

1) Lower tooling costs can give explosive forming an economic advantage over other forming techniques, particularly where quantity of parts to be produced is small.

2) Savings in capital investment can frequently be realized when equipment to form a part by conventional processes is not in the possession of a fabricator.

3) Improved dimensional accuracy of parts can be obtained in many instances through better control of spring-back.

4) Elimination of the solid driving member (e.g., punch, expander segment, and so on) can lead to better surface condition on formed parts.

5) Material can often be deformed further in the cold state than by static deformation procedures, thereby reducing the number of intermediate anneals required. Maximum deformation obtainable does not appear to exceed normal static elongation limits, however.

6) Performance and examination of parts explosively formed so far has shown that the explosive forming process imparts no deleterious effects to metals.

7) Explosive forming is capable of shaping parts difficult or impossible to produce by other means (e.g. a part involving re-entrant angles or a large part requiring forces beyond the capabilities of existing equipment).

In summary, therefore, high explosive, open-die forming appears best suited, economically and practically, to low-volume production of relatively large parts. The correlation that low explosive closed-die forming should be mainly applicable to high-volume production of comparatively small parts seems to be valid. In any event, the designer now has at hand a new concept for the fabrication of metal objects, and there have been sufficient demonstrations of the merits of the process to believe that the concept has commercial utility.

CONTINUOUS CASTING OF ALUMINUM

Six of the most widely used aluminum continuous casting processes are here described, along with their potentialities and drawbacks.

by G. C. Fear

TRANSFORMATION of molten aluminum into relatively low-gage cast strip in one operation has always been economically attractive, since the conventional ingot casting, sawing, preheating, and breakdown hot rolling processes are virtually eliminated; cast strip is eminently suitable either for hot rolling to still lower gages, at a saving in power compared to cold rolling, or for coiling for subsequent cold rolling. It is further attractive to the small-and medium-size users of certain grades of semi-fabricated aluminum strip and sheet, in that it allows installing relatively low-cost equipment in inexpensive buildings of quite small area.

Operators generally agree that a prerequisite for successful operation of any casting machine is clean, low gas content metal at a uniform temperature. Furnace designers and operators can achieve this—it now remains for the casting machines to perform the transformation to cast bar or strip. Close attention must thus be given to the link between the holding furnace and any moving mold casting machine—namely the launder and distribution system, with its associated flow control equipment. In the development of continuous casting machines, much time and engineering effort has been directed to the design of this link, resulting in designs using totally enclosed launders, open launders, heated launders, and insulated launders. Most launders are as short as possible, to minimize turbulence and the possibility of disturbing the heat balance of the continuous system.

Most casting processes feature two devices for metering molten metal to the casting machines. The first is usually an anti-surge device and may take the form of an automatic taphole poker augmented by a reservoir with dip tube. The second is a vernier device that may be controlled manually by a screw, levers, and so on, or automatically by pneumatic or electrical means. Successful operation of moving mold continuous casting machines has been greatly assisted by the attention given to feed arrangements.

In true continuous casting, molten metal is fed without interruption into a mold, where it freezes and is withdrawn as a solid. The mold may have stationary, vibrating, or oscillating walls, or may have rotating rolls or endless belts or a combination of these. Between 1930 and 1955, the major development of moving mold machines for the casting of aluminum took place. Of these processes, many have reached operation; six will be discussed in brief but specific terms.

The first group of moving mold casting machines comprises a combination of a rotating wheel and an endless flexible belt—the Properzi process, the Rigamonti process, and the Rotary Strip Casting process.

Properzi process

The Properzi process produces cast bar and redraw rod. It is the most widely used of the moving mold casting processes, and was probably the first to compete successfully with conventional rod rolling mills. F. R. Nichols, whose company is one of the outstanding users of this equipment, listed about 35 installations prior to 1956.[1]

Fig. 1 shows a schematic layout of the Properzi principle, including the belt, cooling system, and path of the cast bar. The first Properzi machines were built by S. p. A. Continuus, Milan, Italy, for producing lead wire for shot, but during World War II they were developed for the manufacture of zinc wire for metallizing applications. Post-war interest in aluminum wire led Properzi to enlarge the machines and the first aluminum unit produced a cast bar section of 0.5 sq in. In later machines (Fig. 2) cross section has been increased, producing a triangular-type section larger than 1.5 sq in.

The casting wheel has a copper rim and iron side plates, and is kept full of water; the groove in the wheel is closed by a relatively thick steel belt maintained under tension and cooled by a water spray system. In some models the whole lower portion of the wheel is immersed in a water tank.

Molten metal from a holding furnace passes to a large cast-iron holding pot, where a form of needle valve meters the flow into and through a cast iron spout. The tip of this spout enters the wheel cavity and should be slightly immersed in the pool of metal in the wheel. During passage of the metal from the inlet to the outlet positions of the wheel, an angular distance of about 180°, complete freezing of the cross section takes place.

G. C. FEAR is with Aluminium Laboratories Ltd., Montreal, Quebec, Canada. This paper was presented at the AIME New England Regional Conference, Hartford, Conn., May 1959.

The usual casting speed of the Properzi machine is in the range of 24 to 36 fpm, equivalent to approximately 3200 to 4700 lb per hr, giving a bar exit temperature of around 900°F. From the casting machine, the bar passes almost vertically over the operator's head to a rolling mill.

The rolling mill with which the later Properzi machines are synchronized is a 13-stand unit capable of reducing the bar from the original 1.5 sq in. to wire rod of approximately ⅜ in. diam. Each stand of the mill has three rolls located at angles of 120° to each other, the roll arrangement being inverted in alternate stands.

The original Properzi equipment employed for the production of aluminum cast bar was by no means trouble-free. The holding pot and heavy cast-iron pouring spout required considerable preheating to avoid freeze-up, and occasionally the tip of the pouring spout broke off into the cast bar. Control of the operation was impeded by the sluggish and erratic response of the needle valve arrangement and the inability of the operator to view the metal level in the wheel cavity. Poor heat transfer properties of the equipment also lead to inefficient and unsteady cooling conditions.

Design changes proved experimentally and in production with Aluminium Ltd. Group Companies and others have increased output and improved the operation generally, bringing about higher quality and efficiency. The Properzi process is now simple and economical to operate and suitable for producing wire similar to that produced by conventional rolling and drawing techniques.

Rigamonti process

There is close similarity in general layout between the Properzi machine and Rigamonti's modification of the Properzi principle. The Rigamonti machine is mounted at a different angle, allowing the casting to emerge and move forward at just above floor level (Fig. 3); in the Properzi equipment the cast bar passes overhead as it emerges from the machine in a nearly vertical direction. In both the Rigamonti and Properzi machines the cast slab or bar is formed within the closed loop of the belt and, therefore, has to be deflected to one side in order to pass on to a rolling mill. This feature limits the width of slab that can be produced.

The basic Rigamonti machine uses a partially open wheel in which a pool of water is retained. Metal is fed to the wheel at the 11 o'clock position by means of a preheated steel launder. The steel belt is cooled by water sprays. The wheel is driven through an infinitely variable reduction gear, the operation being controlled by varying the wheel speed to keep the pool level constant.

Slabs cast on the Rigamonti machine (Fig. 4) have usually been around 2 and 4 in. wide and ¾ to 1½ in. thick, but 7 to 8 in. widths can be produced, though with considerable difficulty because of the necessity of directing the cast slab to one side. In general, the best casting conditions have been found to be with molten metal temperature of approximately 1300°F and a casting speed between 12 and 30 fpm. The quantity of cooling water used is 18.5 to 26.5 gpm, and the slab surface temperature under these conditions is generally around 750°F.

Major disadvantages of the Rigamonti process are the presence of appreciable surface exudation on the belt side of the slab, and the rapid distortion of the steel belts. The basic Rigamonti casting process is in use today at the Rigamonti works in Milan, Italy; at Fabrique d'Emballages Metalliques, S. A.; Fribourg, Switzerland; and John Dale Ltd., St. Albans, England. The Rigamonti machines at the Coors Porcelain Co., Golden, Colo., and at Enfield Rolling Mills Ltd., Bradford, England, have been appreciably modified to improve their operation.

Aluminium Laboratories' rotary strip casting process

A major disadvantage of both the Properzi and Rigamonti machines is the limited width that can be produced. In order to produce wider material and improve the general operation of the machine, new designs were evolved by Aluminium Laboratories Ltd. in Banbury, England, and the Pechiney organization in France.

In these machines (Fig. 5) the steel belt loop is arranged outside the casting wheel and there can be straight-through passage of the cast slab. No

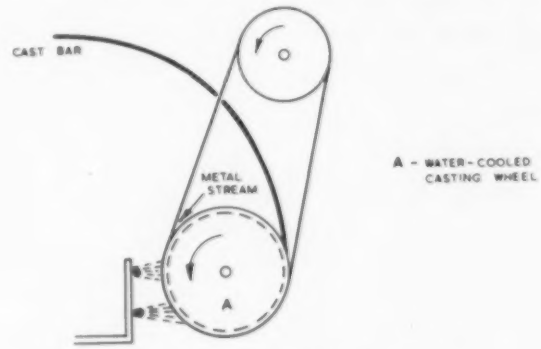


Fig. 1—Properzi casting process.

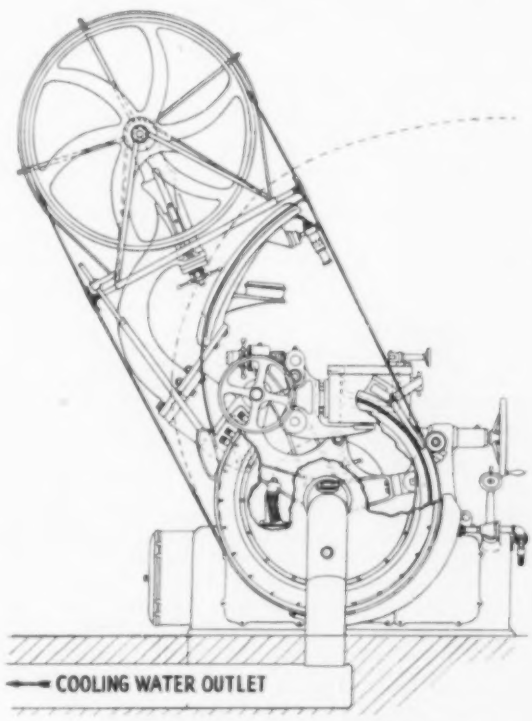


Fig. 2—Properzi No. 6 casting machine.

width limitation is then imposed by the belt layout, and visibility of the liquid pool where the metal enters the wheel cavity is greatly improved.

In the latest model, (Fig. 6) the mold wheel is made of forged steel and has an outside diameter of 40 in. The steel belt passes over a pressure roll and is kept under tension by means of air pressure cylinders acting on the tensioning roll. The machine has an accurately controlled continuously variable speed range up to 35 fpm. The wheel interior is cooled by one or two water jets, depending on the width being cast. These jets are located to apply a fine spray to the inside face and utilize the latent heat cooling principle. The belt, 0.064 in. thick mild steel, is cooled by a nozzle located between the cheeks of the pressure roll, and again by means of a spray box that gives a uniform water curtain over the whole slab width.

Liquid metal is fed into the wheel near the top and removed near the bottom of the periphery. Solidification takes place steadily as the strip travels around the cooled casting wheel, and at the exit position it is completely solid and cooled to around 930°F, a temperature satisfactory for production of an acceptable product. Casting speed depends upon the thickness of the cast strip and the alloy being cast. With this particular model, commercially pure aluminum is cast at 27 fpm for ½ in. thick, compared to 15 fpm for ¾ in. thick. Successful results have been obtained with Alcan 1S, 2S, and 3S alloy strip up to 12 in. wide. Development work is still continuing with the casting of alloys AA-3003, AA-5005, AA-5052, AA-5056, and others. For most products a standard slab width of 8 to 10 in. is recommended with a normal thickness of ¾ in. This is suitable for hot rolling with an integrated mill to less than ⅜ in. in one pass and can be subsequently rolled to slug stock gage with a second mill stand in tandem, or alternatively coiled for subsequent cold rolling.

There is evidence to show that rotary strip casting can be a highly efficient and very low-cost method of producing slugs, strip, circles, alucrowns, roll-formed tubes, and sections. If cross-rolling is also employed, wider products, such as starter sheet for roll-bonded panel, and other products can also be manufactured.

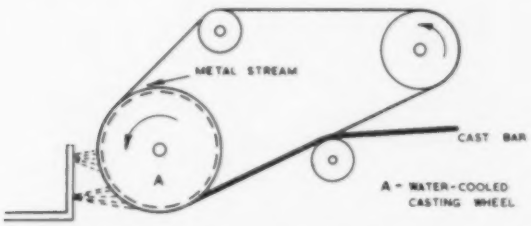


Fig. 3—Rigamonti casting machine.

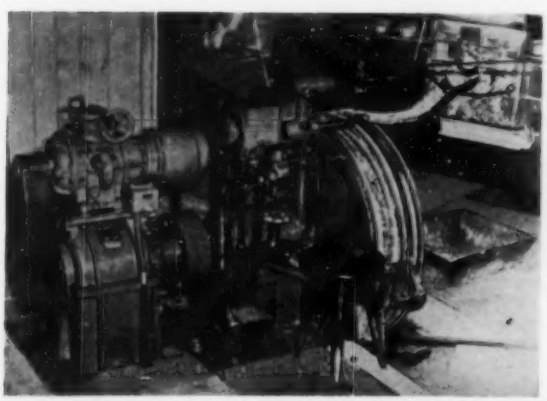


Fig. 4—Modified Rigamonti machine at Aluminiumwerke Rorschach, Switzerland.

Hunter-Douglas process

The second group of moving mold casting machines is the rigid mold type—the Hunter-Douglas process and the Hunter Engineering process.

The Hunter-Douglas process, as described by Hunter and Quadt [3] and patented by Hunter, [3] was developed in the 1940's and has been in successful operation since the early 1950's. It has primarily been used to produce aluminum alloy slab 7 in. wide by 1 in. thick for rolling into venetian blind strip in an integrated operation, although a wider machine is in experimental operation at the Bridgeport Brass Co.

The Hunter-Douglas casting unit (Fig. 7) consists of two sets of half-mold sections with each section attached to the other by means of a chain link similar to the treads of a caterpillar tractor and arranged so that one set of mold sections operates on top of the other. Thus when the half-mold sections come together they form a complete mold. The complete mold moves along in a horizontal plane for a sufficiently long time to allow solidification (about 30 in.), and then continues around to complete the cycle while the slab moves along into a holding oven or tandem rolling mill. Each half-mold section is accurately machined to the required shape of the slab and is cooled by water circulated to the molds by means of ingeniously arranged rubber hoses that revolve with the molds from the main drive stand.

Casting is at a rate of 1800 to 7000 lb per hr, depending on the alloy being cast, and at temperatures of 750 to 1000°F. depending on the chain speed and the mass of the bar. Common alloy, or compositions not prone to coring or other metallurgical segregation, can be rolled continuously from the casting operation, but any or all alloy products may be cut off in approximately 60 ft lengths and held in a furnace maintained at rolling temperature. Hunter-Douglas uses two alloys for venetian blind stock that do not require further treatment prior to hot rolling, although an annealing operation is required before the necessary cold-rolling to final gage for venetian blind strip production.

This very efficient integrated process has produced millions of pounds of entirely satisfactory venetian blind stock at a unit price which has placed the Hunter-Douglas operation in a very favorable position in a highly competitive market.

Hunter Engineering process

This process has recently been brought into successful production. It has been described by Church,[4] and is covered by Hunter patents.[5, 6]

The installation consists of a combination melting and holding furnace, a continuous casting machine, a leveller, a shear, an edge miller, and a coiler. From the holding hearth, molten metal flows horizontally from a tap-out box through a launder, then up through a spreader that distributes it uniformly across the width of the casting machine rolls.

The molten bath in the tap-out box is held at a constant level slightly above the center line of the rolls.

These rolls not only serve as a mold, but also as a heat sink and a source of motive power, and are rated for casting approximately 3 to 4 million lb before replacement due to excessive crazing.

As the molten metal leaves the tip and contacts the roll shells, latent heat of fusion is given up to the thick shells, which act as heat sinks for this purpose, bringing about solidification. During the remainder of the casting roll's revolution the absorbed heat is transferred to and carried off by the water circulating through passages machined into the roll (Fig. 8). Also, as the rolls turn, the path of the solidifying and solidified metal converges and the metal receives a hot pass or hot reduction. It is reported that roll separating forces and roll driving torque are of a magnitude typical of a hot rolling operation.

The temperature of the molten metal is critical, depending partly upon the alloy cast. The preferred practice is to hold the metal at as low a temperature as possible without freezing off the cycle, thus keeping grain size as small as possible, and promoting rapid solidification.

The 40-in. machine at Hunter Engineering produces 38-in. strip at a rate of 3 to 4 fpm. As the strip emerges from the machine it is looped down into a leveller, passes through an edge miller, and is wound into coil form in the up-coiler. When the coil reaches a predetermined weight (3,000 to 8,000 lb) the strip is sheared, the coil removed, and the spooling of another coil is commenced.

Well over 20 million lb of aluminum sheet has been cast at Hunter Engineering since the first unit was put into regular production in 1957. Other Hunter Engineering machines are installed at Nichols Wire and Aluminum Co. and United Pacific Aluminum Corp. and these are successfully operating on the production of aluminum and medium-strength aluminum alloys for painted strip and other commercial applications.

It is reported that strip is cast by this process in alloys AA-110, 3003, 5005, 5050, 5052 and 6061, and others. Metallurgically the structure of the sheet is reasonably fine-grained and the surface quality is good.

Hazelett process

The third group of moving mold machines—the Hazelett process—consists of a combination of two endless flexible belts.

By 1954, substantial progress had been made with the Hazelett flexible belt type casting machine[7] and the properties of commercially pure aluminum cast strip were found to be quite promising, although the material was coarse-grained after reductions of up to 94 pct, and was not internally sound. It was free of surface segregation, however, and selected samples indicated that the mechanical properties of sheet produced from it were similar to the properties of sheet produced by conventional methods. These results aroused considerable interest in the process, and in 1957 a machine suitable for producing strip up to 36 in. wide was acquired by the Aluminum Ltd. group for development and pilot plant operation. Other units were acquired by the Kaiser Aluminum and Chemical Corp., the Aluminum Co. of America, the Scovill Manufacturing Co. and Bridgeport Rolling Mills Co.

Subsequently, Aluminum Laboratories Ltd. acquired, subject to licenses previously granted, exclusive rights to the application of the Hazelett patent for the casting of aluminum, magnesium, and their alloys.

The present Hazelett process (Fig. 9), can be summarized quite briefly by stating that molten metal is introduced between two mild steel belts approximately 0.030 in. thick, and led around suitable support rollers and discs. Thickness of the cast slab is controlled by the distance between adjacent lengths of the two belts, and gage tolerance of cast material has been found to be well within conventional hot rolling tolerances. Width of strip is controlled by positioning of the side dams that are in the form of small rectangular aluminum blocks threaded along stainless-steel straps that travel on the surface of the lower belt in the manner of caterpillar tracks. Tracking of the belts is achieved by automatic means, and their linear speed is variable from 0 to 80 fpm.

The Hazelett casting machine embodies the principle of extremely fast chilling of the molten metal. Cooling water is applied to both flexible belts from the inside of the loops along the straight sections by a series of high-velocity water spray jets angled in the direction of the solidifying strip's movement. The majority of water applied by the first row of jets is scooped from the belt before the water from the second row of jets touches the belt. This mater-

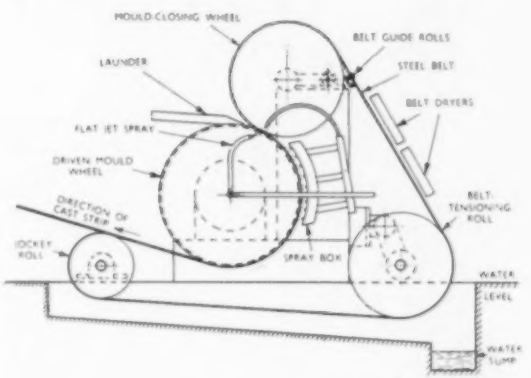


Fig. 5—Rotary strip-casting machine at Aluminium Laboratories in Banbury, England.

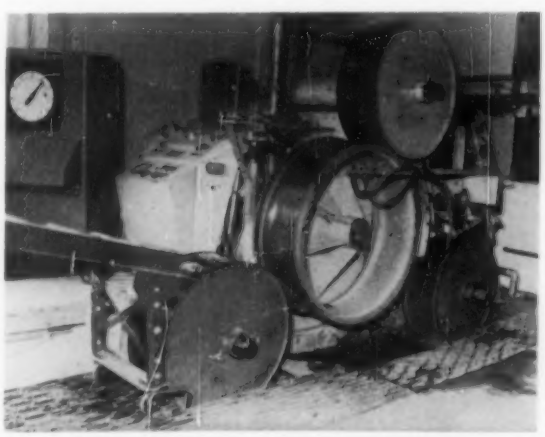


Fig. 6—Rotary strip-casting machine, model No. 6.

ially assists the rate of heat removal by reducing turbulence to a minimum, and assures that only a thin high-velocity stream of uniform temperature passes along the belt surface.

To further control the rate of heat transfer from the molten metal, the flexible belts' faces are treated with belt dressings. These dressings, with a critical insulating value, consist of various mixtures of insulating compounds such as cellite. They are applied with suitable bonds, such as epoxy resins, and materially assist the production of material having good surface finish, free from shrink and associated micro-cracking, segregation, and so on. The exact type of belt dressing to suit each alloy and casting condition is the subject of experimentation, but dressings have been developed that allow for at least 8 hrs of operation prior to a belt change that necessitates approximately ½ hr downtime. Thus, with a 36 in. wide machine casting commercially pure aluminum, having an exit temperature of approximately 1020°F. at the normal rate of 7 to 8 fpm for 1 in. thick strip, 150,000 lb of metal can be cast between belt changes. The retired belt is cleaned, redressed and ready for re-use until excessive distortion dictates its ultimate discard.

To date, Alcan 1S, 2S, and 3S alloys have been cast with success at thicknesses of ½ in., 1 in., and 1½ in., and at speeds of approximately 17, 8, and 4 fpm, respectively, resulting in a relatively constant machine output rate. Metallurgical properties of cast strip, subsequently hot rolled, cold rolled, annealed, and so on indicate that the crystal structure is comparable to that of material in conventional processing.[12] Given adequate cold reduction with or without inter-annealing, Alcan 2S strip has been successfully deep drawn for the production of cans with an extremely low degree of earing, and has also been rolled for both decorative and cigarette foil usage, down to a thickness of 9 μ.

Recent trials with aluminum alloys indicate that this machine will be suitable for the production of AA-3003 and AA-5005 alloys, and spot trials with AA-5052 and AA-5056 alloys have also been very encouraging.

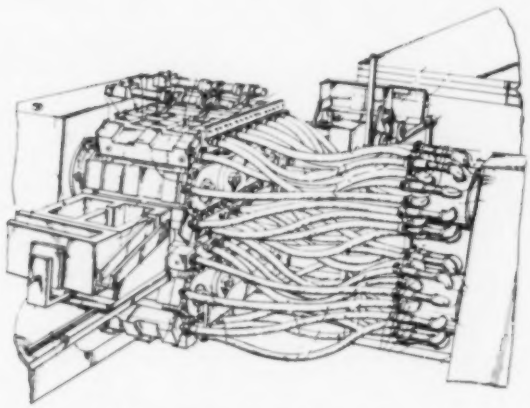


Fig. 7—The Hunter-Douglas machine.

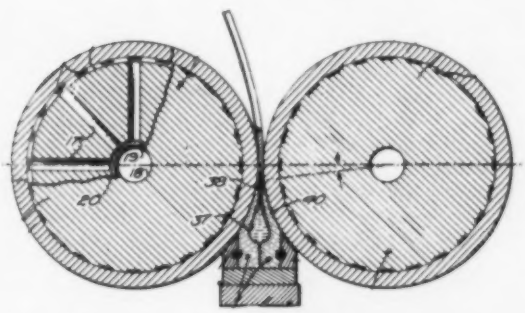


Fig. 8—The Hunter Engineering Process, casting and rolling principle.

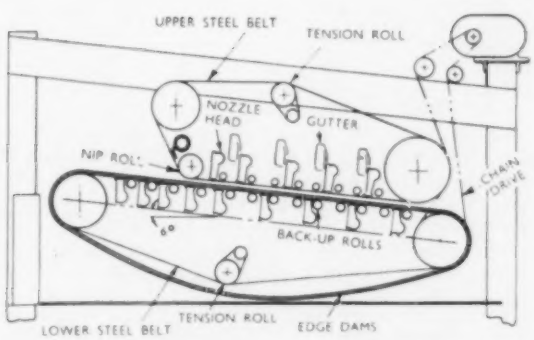


Fig. 9—Basic principles of the Hazelett machine.

Conclusions

In concluding this brief summary of six of the moving mold casting machines presently in commercial operation, it would be unfair to give any indication of preference for any particular process. Each undoubtedly has attributes that best suit its installation for the production of particular commodities.

To date, the Properzi machine reigns supreme in the field of bar section for redraw rod production. The Rigamonti and the Hunter-Douglas processes are proven for the production of cast strip up to approximately 7 in. wide, while the Rotary Strip Casting process is proven in the field of up to 12 in. wide strip production. The Hunter Engineering and the Hazelett processes are proven in the field of up to 36 in. wide production, both processes being eminently suitable for casting wider, say, up to 60 in. material.

The labor content of all the moving mold casting processes is quite similar. There is one basic difference between the processes, however, and that lies in the potential production rates. The Hunter Engineering process produces ¼ in. thick strip that is coiled ready for subsequent rerolling, whereas all other moving mold processes produce ¾ to 1 in. thick material, and achieve resultant higher ouput rates. Thus, the Hunter Engineering machine is ideal for finished outputs approaching 5,000 tons per yr of 36 in. wide material, whereas at a similar width the Hazelett machine is suitable for annual outputs of over 30,000 tons.

References

[1] F. R. Nichols: *The Progress of the Properzi Process*, Wire & Wire Products, vol. 31, Oct. 1956.
[2] J. L. Hunter and R. A. Quadt: *Aluminum Strip Rolled from Continuously Cast Bar*, Iron Age, vol. 169, April 10, 1952, pp. 118-120.
[3] U.S. Patent No. 2,631,343, 1953.
[4] F. L. Church: *Shortcut to Sheet*, Modern Metals, vol. 15, no. 2, March 1959, pp. 30-36.
[5] U.S. Patent No. 2,790,216, 1957.
U.S. Patent No. 2,850,776, 1958.
[6] Canadian Patent No. 569,390, 1959.
[7] U.S. Patent No. 2,640,235, and additional applications in the US and other countries.

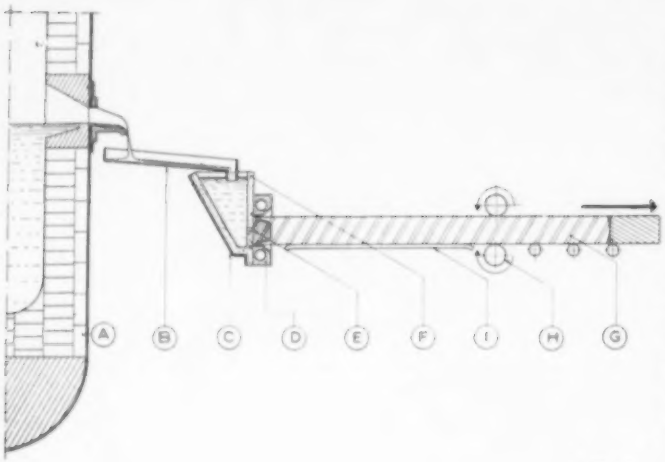


Fig. 1

Ugine Venthon Process

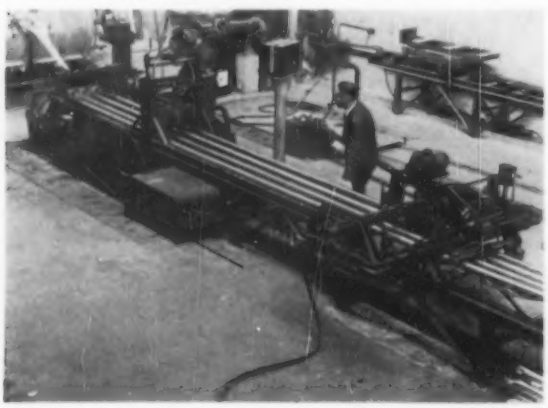
Continuing with "Continuous Casting of Aluminum," here is a description of a recently-developed, horizontal casting process which offers considerable operational flexibility.

by P. Angleys

Many processes are now in use for the horizontal casting of metals. In spite of their diversity, they all derive from one of the two following principles: solidification of the metal in a mobile-walled mold, which thus avoids relative movement between the mold wall and the metal; or solidification in a fixed-walled mold through which the metal is withdrawn as it freezes. The process operated at the Venthon (Savoie) plant of the Societe D'Electrochemie, d'-Electrometallurgie et des Acieries d'Ugine is based on the latter principle.

This process was first developed for casting the aluminum busbars required for the extension of the electrolysis section of the plant; thus, the need for rolled bars, in all the lengths and sections involved, was avoided. Several thousand tons of busbars have been cast by this process for many plants, such as Edea (Alucam), Baie Comeau (Canadian British Aluminium Co.), Bolzano (Montecatini), Noguères (Pechiney) etc. A wide range of cross sections has been produced, from 120x20 mm to 630x 140 mm.

Fig. 2



The principle of the process is illustrated in Fig. 1. The metal flows from the furnace, A, through the launder, B, into the container, C. It passes into the mold, D, through the hole, E, pierced in the refractory plate, F. The ingot, G, is continuously withdrawn from the mold by the rollers, H, being cooled as it emerges by the peripheral water sprays, K, and supported by the table, I. A flying saw, J, can be clamped to the ingot to cut through it without interrupting the casting (Fig. 2).

The development of the process involved the solution of two problems. The first was the stabilizing of the solidification front deriving from the initial contact between the metal and the mold, and this was achieved by limiting the backward displacement of the front by means of the refractory plate, F, and its forward displacement by direct chilling with peripheral water sprays, K. The second problem was the continuous lubrication of the zone of contact between the metal and the mold. Experience has shown the necessity of this if truly continuous casting is to be achieved with metal-walled molds.

Possibilities of the process

Pure aluminum

By merely changing the mold, the same machine can cast round or rectangular sections and, depending on their dimensions, several bars simultaneously. It is difficult to assign limits to these dimensions; rectangular bars ranging from 300x15 mm up to 700x200 mm have been cast. In particular, the section 920x25 mm can be direct cold-rolled giving sheets free from blister and with low-earing. Round bars from 30 mm diam upwards can be cast with ease.

Casting speeds are variable, being dependent upon cross section, decantation, metal temperature, and so on. They range from about 20 cm per min for very thick bars to 1 m per min for thinner ones, these being average figures, however, and not necessarily the maxima possible.

The process is also suitable for certain special cross sections and, for example, thick-walled tubes. The latter are being cast on a production scale in France and England as roughing ingots in AlSn bearing alloy. (*See Metaux, Corrosion, Industries*, Sept. 1959).

Aluminium alloys

Very little systematic work has yet been carried out on alloys, as almost all the development has been confined to pure aluminium. However, such alloys as AG3, AM1, AGS, and AZ5GU have been cast into round and square sections without difficulty. And no reason can be seen why an alloy, which can be cast by the usual vertical process, could not be cast by the Ugine process.

P. ANGLEYS is with Venthon plant of the Societe d'Electro-Chimie, d'Electro-Metallurgie et des Acieries Electriques d'Ugine at Albertville (Savoie), France.

The Fracture Conference

A brief summary of the Swampscott Conference on Atomic Mechanisms of Fracture...

by B. L. Averbach

An international Conference on the Atomic Mechanisms of Fracture was held in Swampscott, Mass. April 12-16, 1959. This Conference was sponsored by the National Science Foundation, the Office of Naval Research, the Air Force Office of Scientific Research, and the Ship Structure Committee.

Late in 1957, it appeared that theories concerned with the mechanisms of fracture had arrived at a point where it was necessary that experimentalists and theorists meet face-to-face to discuss the divergent viewpoints which had developed. There had been considerable success with dislocation models in the field of plastic flow, and it appeared that the neglected field of fracture could benefit from a consolidation of the defect models proposed for various types of fracture. Therefore, it was decided to hold a conference which would include fracture phenomena in metals, ceramics, and polymers, and would consider the mechanisms of cleavage, fatigue, and ductile and high-temperature fractures.

In the first paper A. H. Cottrell brought into focus the theoretical aspects of most of the fracture mechanisms considered at the conference. This was followed by nine papers which were concerned with mechanisms of cleavage fracture, and a group of six papers on fracture phenomena in glasses, oxides, and polymers. Five papers were presented on fatigue . . . three on ductile fracture . . . and the formal sessions were brought to a close by papers on high-temperature failure, intercrystalline mechanisms, intergranular fracture, and cleavage in refractory metals.

Three summary papers, written after the meeting, are discussed below.

Cleavage fracture

C. S. Barrett pointed out that the dislocation mechanisms of cleavage appear to be firmly established and that considerable sophistication has developed in their application. Current emphasis appears to be on obtaining better understanding of the detailed processes by which dislocations produced during plastic flow are converted into the cavity dislocations of a crack. These theories all stress an effective surface energy which is associated with the cleavage processes. At least three surface energies were distinguished: γ_c, the true surface energy of the crack, γ_1, the effective surface energy associated with the critical crack size (including the plastic deformation energy in the nearby surroundings), and γ_2, the effective surface energy associated with the propagation of the crack through the entire specimen. Unfortunately, an independent method of obtaining these effective surface energies has not been devised, and this seems necessary in order to firmly establish this concept.

An additional point was the rather uncertain role played by twinning. It was shown that cracks can be initiated at the intersection of two twins, and that the twins themselves may contain cracks apparently formed during twin generation. Zener suggested that the value of γ_2 may decrease and approach γ_1 at low temperatures, since the shearing process involved in tearing the regions between adjacent cleavage planes may become adiabatic.

B. L. AVERBACH is Associate Professor, Massachusetts Institute of Technology, Cambridge, Mass.

Fatigue and ductile fracture

R. W. K. Honeycombe suggested that there should be considerable emphasis in the immediate future on the metallographic features of fatigue and that this should be closely correlated with the mechanical behavior. Considerable skill in the observation of extrusions and intrusions at the surface has been developed, but it is evident that such variables as temperature, strain level, frequency environment, variations in the stress program, the fatigue limit, and crack propagation must be considered. Areas which require research and study in ductile fracture include the role of inclusions and second phases on the propagation of ductile cracks, transition from single crystal fractures to polycrystalline fractures, and detailed mechanisms in the cup-cone regions of fracture.

Experimental methods

It was quite evident that structure and metallography were very closely associated with dislocation mechanisms in the work on metals. On the other hand, relatively little correlation with structure has been made for glasses and polymers, and the emphasis appears to be on the chemical effects in glasses and on the velocity effects in plastics. It is also evident that there have been relatively few fatigue studies on polymers and few microstructural studies on ceramics. On the other hand, the very fine experimental work on stress propagation in polymers appears to be absent in opaque materials because of the obvious experimental difficulties. The experimental methods and the theoretical approaches seem to be different for metals, ceramics, and polymers, and very little attempt has been made to apply the techniques from one field in another.

It was also apparent that there have been relatively few applications of fundamental concepts to the more complicated engineering materials. Brittle failure of martensitic and bainitic steels does not appear to have been studied in detail, and the influence of chemistry on microstructure and substructure has not been well established in metals. These considerations are just beginning to be introduced in the studies of ceramics. The microstructure of polymers rarely appears as a consideration in these studies, and with the advent of crystalline polymers it may be helpful to apply the approaches of physical metallurgy in correlations of the fracture properties. Studies of ductile failure are just underway, and this type of fracture may become very important in high-strength materials which exhibit very limited ductility.

Proceedings of the meeting, entitled *Conference on Fracture*, were published by the Technology Press of MIT and John Wiley & Sons, Inc. and copies are available for $17.50.

THE MIXING LADLE, A New Metallurgical Tool

Here is an interesting new approach to metallurgical problems requiring an intense mixing of liquid iron and an intimate contact between molten iron and solid or gaseous agents.

by Sven Eketorp

THE importance of stirring and mixing in order to carry out metallurgical reactions rapidly has become more and more recognized in recent years. In many cases it is not sufficient that the thermodynamic conditions be fulfilled for a desired reaction to take place, but the velocity of the reaction must be maintained by adding or removing the reactants from the reaction zone at sufficient speed. This is often achieved by mixing, which accomplishes both an increase of the interface and also an equalization of the concentration gradients within each phase.

There are several ways to carry out such a mixing. A method which has long been used is to achieve it electrically in a high-frequency furnace, or in an electric-arc furnace with a stirring coil under the bottom. An effective method is to use gas for the mixing, which has been done now for 100 years in the bessemer processes. Gas has also been used for pure mixing of metal in a ladle, by Spire[1] for instance. In this connection, one should perhaps also point out the importance of the boil for the mixing in steelmaking furnaces.

Mixing is especially important when it is necessary to create contact between a solid pulverulent substance and liquid pig iron, which takes place when desulfurizing pig iron with lime or calcium carbide where the speed of desulfurization depends entirely on the contact between the desulfurization medium and the pig iron. About 10 years ago at the research department in Domnarvet, Sweden, Bo Kalling and his associates developed a desulfurization process in which the pig iron was brought into intimate contact with lime powder in a rapidly rotating kiln.[2, 3, 4] This process is now used in many plants in Sweden as well as in other countries. Trentini, Wahl, and Allard,[5] have worked out a desulfurizing method at IRSID in France in which lime powder, together with nitrogen or air is injected into a pig iron bath through a number of nozzles.

A horizontally supported kiln in itself is a simple apparatus, but its use in steel mills has met with difficulties, one reason being that it holds relatively little pig iron; therefore, it becomes unwieldy, especially in steel plants where it may be difficult to introduce time-and labor-consuming processes within existing operations. An easier-to-operate apparatus was, thus, considered desirable, and in this situation the so-called *mixing or shaking ladle* was developed. The first trials with this equipment were carried out in February 1958, and subsequent results have created great interest.

SVEN EKETORP is with the Research Department of Stora Kopparbergs Bergslags Aktiebolag at Domnarvet, Sweden.

Principle of mixing ladle

The idea on which the mixing ladle is based has been known and utilized on a small scale for a very long time. The liquid has the same motion as is obtained when you shake a glass of water, letting the glass describe a small circular motion, without having the glass rotate around its own axis, which is the motion of a lump of ice in a cocktail glass. Professor Bo Kalling adopted this idea and suggested that we develop it on a larger scale.

In order to investigate more closely what takes place when liquid is brought into motion in a container in this manner, model tests were carried out on a large scale with water. A vessel with dimensions given at the lower right on Fig. 1, was filled with 308 liters of water (corresponding to 2 metric tons of pig iron), so that the bath depth at rest was 490 mm.

The vessel was brought into an eccentric motion with varying eccentricities at different speeds of revolution. The value stated for the eccentricity is equal to the radius in mm of the small circle which is described by the center of the vessel. During rotation, the surface of the bath assumed a position principally as shown in Fig. 1. The diagram shows the height of the wave during rotation, under different conditions. For instance, at 61 mm eccentricity the surface *rocks* around without any great degree of mixing taking place up to about 50 rpm. At this critical speed a characteristic wave motion is created which looks like a *breaker* and one can clearly see that when such a wave is obtained the conditions for stirring are quite different and much more favorable than at lower revolutions. Of course, a certain amount of mixing is always obtained in the liquid by its motion relative to the wall of the vessel. The diagram shows a definite break in the curve of the bath height at this critical speed. During continued increase of the rpm, the bath height is further increased and the liquid surface more and more takes the form of a paraboloid whose axis is displaced from the center of the vessel and rotates around the axis of the container at a distance determined by the chosen eccentricity. At a speed too high above the critical speed, the mixing effect does not seem to be as intensive as closer to the critical

Table I. Desulfurizing pig iron in the mixing ladle

Heat No.	Pig Iron, Metric Tons	CaO, Pct	Coke Breeze, Pct	$CaCO_3$, Pct	Eccentricity, Mm	Speed, Rpm	Shaking Time, Min	Analyses C, Pct	Analyses Si, Pct	Analyses S, Pct
SK6	2.6	1.5	0.6	—	61	70	0	3.50	0.40	0.213
							5	3.70	0.35	0.055
							10	3.74	0.34	0.032
							20	3.79	0.34	0.020
							30	3.88	0.32	0.013
SK9	2.3	1.7	0.7	0.10	61	75	0	3.46	0.07	0.163
							5	3.48	0.03	0.042
							10	3.62	0.02	0.020
							20	3.62	0.02	0.011
							30	3.62	0.02	0.009
SK61	2.5	1.6	0.8	0.08	79	60	0	4.32	0.53	0.052
							10	—	—	0.007
							15	—	—	0.004
							20	4.34	0.53	0.004

velocity. At a lower eccentricity, 26 mm for instance, the above wave motion is obtained at a somewhat higher speed—about 60 rpm.

Fig. 2 gives a summary of the test showing the speed of revolution at beginning wave formation and the bath depths for different values of eccentricity. For practical use, excessive wave height is, of course, undesirable, and for this reason an eccentricity between 50 and 100 mm has been used in most cases.

Metallurgical uses

The mixing ladle has proved to be an excellent metallurgical tool wherever it is necessary to obtain good mixing, whether in the pig iron or the steel bath itself, or to create good contact between pig iron and a solid, fluid, or gaseous reactant. A few typical fields of use will be described herewith. The reported results have been obtained in the research department at Domnarvet, Sweden, in a mixing ladle with a capacity of 3 metric tons.

a) Desulfurization

Desulfurization of pig iron with lime requires, in addition to reducing conditions, as intimate contact as possible between the pig iron and the finely powdered burned lime. Table I shows the results from some desulfurization tests in the mixing ladle where the degree of desulfurization was about 95 pct. The sulfur content can be lowered to about 0.010 pct S, even at such high original contents as about 0.2 pct. The lime addition was from 1.5 to 2.3 pct of the pig iron weight. On the basis of experience with desulfurization in a rotary kiln with a capacity of 3 tons, compared to full-scale installations of 15 to 30 tons, one can predict considerably lower lime consumption in larger ladles than used in the reported trials. A small amount of coke breeze was added, because otherwise it was difficult to obtain a strongly reducing atmosphere in this small installation, in which a maximum of three tests per day were run.

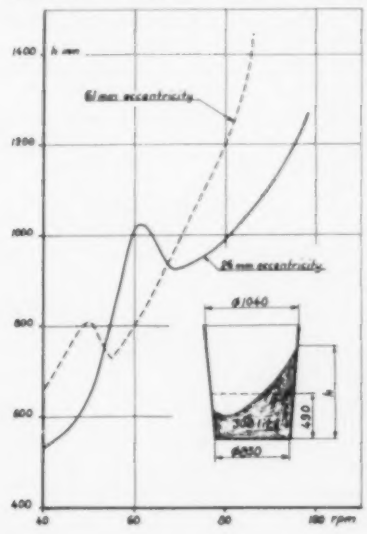


Fig. 1 — Wave height as a function of speed of revolution.

Based on experience with rotary kilns, addition of coke breeze will not be necessary in full-scale operation. In two of the reported tests, a small amount of soda ash was added, as it was found that soda ash prevented the lime from adhering to the wall of the ladle, and at the same time decreased the amount of iron granules in the lime powder. Compared to the rotary kiln, it was discovered that the amount of iron in the lime was considerably lower, possibly because the mixture of iron and lime powder was subjected to a certain centrifugal force during the shaking motion. The temperature of the pig iron during these tests was about 2280°F.

The temperature loss in the mixing ladle will be less than for a corresponding desulfurization in a rotating kiln, partly because the ladle can be well insulated, and partly because the ladle can be made smaller, for the same capacity, than a rotating kiln.

It is interesting to note that the desulfurization of the pig iron is also efficient at low silicon contents. In test SK 9, the final content of silicon was only 0.02 percent, and the principal reduction agent in this case must have been carbon. In conclusion, it can be stated that desulfurization can be carried out easily in a mixing ladle with normal amounts of lime.

b) Recarburization and alloying

Recarburization of pig iron in an ordinary ladle is difficult to accomplish and gives unsatisfactory

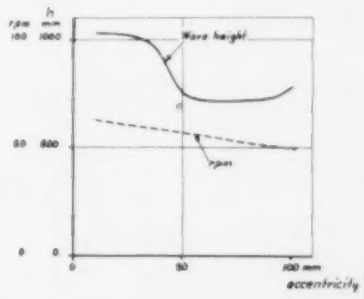


Fig. 2 — Wave height and speed of revolution, for different eccentricities.

results. For successful recarburization with solid carbon, a very good mixing is necessary so that the carbon comes into intimate contact with the pig iron. A rotating furnace has proved efficient, and in the Kaldo furnace at Domnarvet large-scale recarburization tests have been carried out in connection with the manufacture of pig iron with low phosphorous content from basic bessemer iron. The carbon content has, thus, been raised from 1.4 to 3.5 pct with coke breeze by rotation for 10 min.[6]

Also, the mixing ladle has proved quite suitable for recarburizing pig iron, especially when separated from refining processes. Table II describes some recarburization tests with coke breeze where, at the same time, 45 pct ferro silicon and 80 pct ferro manganese were added. The shaking time used in the tests has generally been 5 to 10 min. Normally, a carbon yield of about 80 pct can be expected, provided the pig iron temperature is high enough. Carburizers other than coke breeze can be used.

Recarburization is always accompanied by a considerable temperature loss. The heat of solution for carbon is 5500 Kcal per metric ton per 1 pct C, while the sensible heat is of the same magnitude. When adding coke with 80 pct C and obtaining 80 pct carbon yield, it is necessary to count on a minimum temperature loss of 145°F per percent C. If it is important to maintain the pig iron temperature, it is possible to inject a small amount of oxygen during recarburization and alloying, which will result in a lower yield of the additions and less favorable conditions for subsequent desulfurization.

In our tests, only 45 pct ferro silicon was used, but 75 pct alloy should be more suitable because this material is exothermic. As can be seen from Table II, the yield of silicon and manganese is 90 to 100 pct. Silicon has been added to achieve different silicon contents, even so high (test 4) that a very strong graphite precipitation took place. As shall be discussed later, it can be of great importance to have the possibility of adjusting, in this simple manner, the contents of carbon, silicon, and manganese in the pig iron.

c) Prerefining

Desiliconizing can be accomplished in a stationary ladle by oxygen lancing, but such a method has great disadvantages, mainly because mixing of the pig iron bath is insignificant. This results in a higher silicon content at the bottom of the ladle than at the surface. Because of this, the pig iron surface temperature will be higher than in the rest

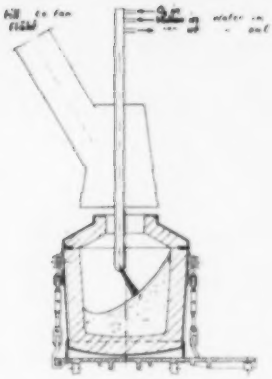


Fig. 3 — Arrangement for preblowing with oxygen in the mixing ladle.

of the bath, thereby causing a certain amount of carbon elimination. Attempts have been made to counteract this disadvantage by carrying out the prerefining while the ladle is being filled.[7, 8]

Through intensive mixing in the ladle, prerefining can be carried out with great precision. A series of tests have been made in which the mixing ladle was equipped with an exhaust hood and a water-cooled lance above the bath (Fig. 3). The results of trial blowings on silicon are shown in Table III.

The effective mixing is proved by the moderate decrease in the carbon content, in spite of the silicon content being lowered from more than 1 pct to 0.10 pct. In test SF 4, the carbon content was, thus, reduced from 3.50 to 3.30 pct, while the silicon content went down from 1.33 to 0.05 pct. In test SF 1, lime was added so that the slag had a basicity of about 1.0, and as a result of this, the FeO content was only 3 to 4 pct. In the other tests, the slag was strongly acid and the iron contents were consequently higher. In SF 1, only a small amount of coolant was added and the temperature was allowed to increase to 2815°F. This probably contributed to the relatively large decrease in the carbon content toward the end of the test. In other tests, the temperature was held at a lower level by cooling with iron ore concentrates or pellets, 4.5 pct of which were added to SF 4.

The oxygen yield, calculated on the basis of the oxidation of silicon in the above tests, is rather low —about 30 pct—which may be due to the oxygen input being high—4 cu m per min—for such a small unit. It should be emphasized that so far we have made only the above tests, and a higher yield can be expected when closer study has been given to such factors as the height of the lance over the bath,

Table II. Recarburizing and Alloying in the Mixing Ladle

Heat No.	Pig Iron, Kg	Additions, Kg	Time, Min	Temp, °C	Analyses, Pct C	Analyses, Pct Si	Analyses, Pct Mn	Yield C	Yield Si	Yield Mn
1[a]	2300	45 coke	0	—	2.70	0.22	0.04			
		59 FeSi (45)	2	—	2.94	1.38	0.71			
		20 FeMn (80)	4	—	3.34	1.34	0.71			
			9	1280	3.48	1.33	0.70	64	101	100
2[a]	2875	60 coke	0	—	3.28	0.43	0.37			
		120 FeSi (45)	10	1255	3.89	2.07	0.93	57	95	112
		20 FeMn (80)								
3[b]	2690	130 FeSi (45)	0	1340	4.30	0.46	—			
			5	1285	3.98	2.33	—	—	91	—
4[b]	2820	125 FeSi (45)	0	1285	3.98	2.33	—			
			5	1265	3.43	4.22	—	—	104	—

[a] Excess coke.
[b] Graphite precipitation.

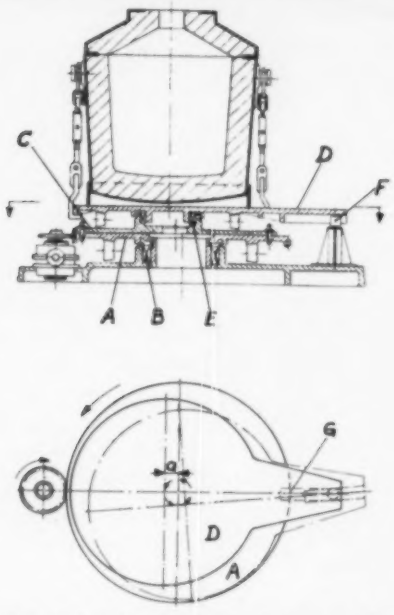


Fig. 4—Design of pilot plant ladle presently in use at Domnarvet.

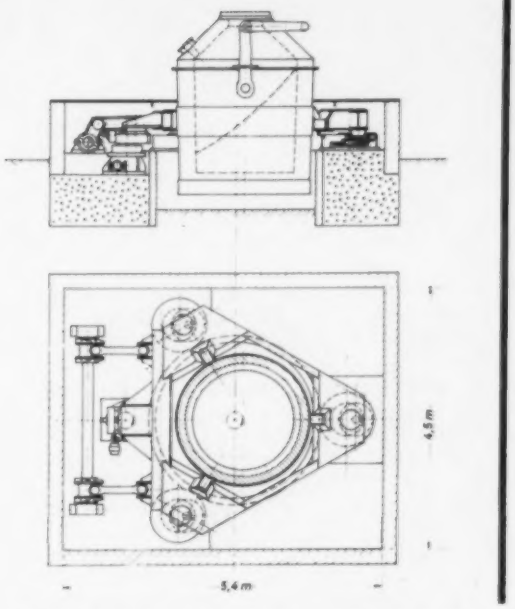


Fig. 5—Shaking ladle design suggested by Gesellschaft für Hüttenwerksanlagen.

the angle of the oxygen jet with the axis of the ladle, the rate of oxygen input, eccentricity, and speed of revolution. Through mixing in a ladle, local high temperatures in the bath are avoided during oxygen blowing.

The design

The pilot plant, which is being used at present in the research department in Domnarvet, is built according to the design shown in Fig. 4. A lower table, A, can be rotated around the bearing, B, by means of a chain drive. On top of this table a disc, C, is placed more or less eccentrically; for instance, at the distance, A. The upper table, D, on which the ladle is placed, can rotate on rollers around the bearing, E. The table, D, with the ladle is prevented from rotating around its own axis during the rotation of the lower table, A, by making it reciprocate about the fixed point, F, in the slot, G. The motion of the center of the ladle in this case will be circular, but as the upper table is fixed in one point, all other points are moving in elliptical paths. It is quite possible to make a design in which each point of the ladle table describes a circle. In order to create the previously described wave and thereby a good mixing, the form of the motion is not essential. For instance, the ladle can have a straight, reciprocal motion with a frequency and stroke equal to the one obtained by circular motion; in this case the steel bath will also rotate inside the ladle.

Many different designs are possible in order to obtain the motion of the mixing ladle, but the most interesting suggestion at the present time has been made by Gesellschaft für Huttenwerksanlagen in Germany; see Fig. 5. The mixing device is arranged in such a manner that the ladle can be lowered into it without any locking arrangement other than three lugs which fit into corresponding slots. The structural frame is supported in three points on strong ball bearings, and the frame with its ladle can be moved in its circular path by means of an eccentric pin which, in this case, is carrying no load. The structural frame is held in position by a special parallelogram guide. The ecentricity and speed of revolution can be regulated.

Table III. Preblowing Basic Bessemer Iron in the Mixing Ladle

Heat No.	Pig Iron, Kg	Conc. or Pellets, Kg/Met Ton	CaO, Kg/Met Ton	O_2, N Cu M/Met Ton	Time, Min	Temp, °C	Pig Iron Analyses, Pct			Slag Analyses, Pct		
							C	Si	Mn	FeO	SiO_2	CaO
SF1	2300	—	—	—	0	1280	3.60	1.29	0.70	—	—	—
		—	22	4.9	3	—	3.60	1.16	0.70	4.4	41.8	40.8
		—	22	5.0	6	1445	3.46	0.92	0.70	4.6	34.1	48.5
		5	22	9.3	11	—	3.24	0.41	0.65	2.3	41.0	42.1
		—	22	11.0	16	1545	3.00	0.03	0.40	3.1	39.6	40.3
		5	88	30.2	16							
SF4	2100	—	—	—	0	—	3.50	1.33	0.44	—	—	—
		—	—	6.2	3.3	1350	3.47	1.07	0.77	33.9	41.5	1.8
		10	5	6.2	6.6	1410	3.40	0.65	0.50	23.0	41.6	10.9
		15	5	6.0	9.8	1460	3.36	0.37	0.31	33.4	36.4	8.4
		20	—	5.8	12.9	1430	3.30	0.05	0.09	35.2	35.6	7.6
		45	10	24.2	12.9							

To facilitate tapping of the pig iron after treatment, a tap hole is provided in the conical part of the ladle. This prevents the powdered lime from following the iron, which may be poured directly from the mixing ladle into a casting machine or into molds. The tap hole is closed with a wooden plug during treatment. After tapping the iron, the ladle is turned upside down to pour out the lime powder.

One of the most important advantages of the mixing ladle is its ease of practical operation. In principle, normal ladles can be used after they have been provided with a conical cover. The cover is necessary during the desulfurization process to achieve reducing conditions, and during oxygen blowing to collect the smoke. During mixing, it is of course necessary to have a cover to prevent the pig iron from being thrown out of the ladle. For handling, the ladle is provided with ordinary trunnions.

An important advantage of the mixing ladle compared to the rotary kiln is that it can be made much smaller and, therefore, cheaper for the same capacity. The height of the wave inside the ladle at the critical speed is 1.4 times the bath depth at rest. For practical use, one should count on a maximum bath height during rotation of 1.6 times that of the bath depth when the ladle is standing still. The ladle can, thus, be filled to about two-thirds. A rotary kiln requires 1.5 to 1.6 cu m furnace volume per metric ton of pig iron, while the corresponding value for the mixing ladle is 0.25 to 0.3 cu m per metric ton.

The mixing ladle, which describes only a small circular path, can effectively be insulated, since stresses on the brick are small. The mixing ladle can, thus, be made for small capacities, even below 5 metric tons of pig iron weight.

Industrial application

In steel mills desulfurization of pig iron with lime powder in a rotary kiln has not been introduced to the extent which might have been expected, considering the results which can be obtained with this process. One reason for this may be the fact that the rotary kiln is too unwieldy. With the mixing ladle, the process is in a new and better position, and it has met with great interest. At present, mixing ladles with capacities up to 80 metric tons pig iron are being planned. Metallurgically, the desulfurization in a mixing ladle is the same as in a rotary kiln, but economically it may be somewhat cheaper.

For steel mills, the possibility of desiliconizing pig iron in a mixing ladle should also be of interest.

However, one field in which the mixing ladle may find immediate use is in foundries for refining low-grade pig iron to a high-grade hematite pig iron. As described above, it is possible to lower the sulfur content of the pig iron in a simple manner and, at the same time, adjust the carbon, silicon, and manganese contents to desired values. In order to produce a high-grade pig iron, it is now necessary to use more or less hematite pig iron in the cupola, but with the possibility of adjusting the analysis afterwards the cupola can be charged with a large quantity of steel scrap, which will lower considerably the cost of the charge.

Tests at Domnarvet have proved that such changes in analyses are quite possible in the mixing ladle, as shown in the following examples of analyses before and after treatment:

	Before	After
C, pct	3.28	3.78
Si, pct	0.43	2.05
Mn, pct	0.37	0.91
S, pct	0.059	0.006

Test pieces were cut from two samples of cast iron, one before and the other after treatment. The untreated iron is white and has high gas content, while the treated iron is gray. Besides obtaining the desired contents of carbon, silicon, and manganese, the sulfur content can be decreased to very low values, which is not possible even with a high-grade pig iron in the charge or in the basic hot-blast cupola.

Foundries often produce cast irons of quite varying analyses, which usually is done by changing the operation of the cupola. With a mixing ladle, combined with a cupola, a base iron with low carbon and silicon contents can be produced cheaply in the cupola, and the desired analyses can then be obtained by adjustment in the ladle.

In Germany, a 3-ton pilot plant mixing ladle has been installed by the Mannesmann-Meer firm in Munchen-Gladbach, and very interesting results have been obtained with desulfurization and alloying. In the same plant, a 15-ton installation is now being planned. The mixing ladle will then replace the fore hearth of the cupola in order to minimize the temperature losses during operation.

Summary

The so-called mixing ladle has been developed at the Research Department at Domnarvet, Sweden, and its use for different metallurgical operations has been studied. The mixing ladle makes possible a very intense mixing action of liquid iron and an intimate contact between the molten iron and solid or gaseous agents. The movement of the ladle resembles that which happens in a glass of whisky when shaken around in a small circle. Interesting results have been obtained with desulfurization of pig iron, carburization with coke breeze, alloying with silicon and manganese, and preblowing with oxygen for removal of silicon.

The mixing ladle should be ideal in all cases in which a good stirring effect is wanted. In steelworks, it will be simpler to use than the rotating furnace formally used in some plants for desulfurization. In foundries it may be used in combination with an acid cupola in which a base iron is made essentially from steel scrap and later carburized, alloyed, and desulfurized in the mixing ladle.

[1] E. Spire: A Ladle Treatment for Desulphurising and Degassing Steel, *Proceedings of Electric Furnace Steel Conference*, AIME, 1951, vol. 9, pp. 75-84.

[2] B. Kalling, C. Danielson, and O. Dragge: Svavelrening av Tackjarn med Kalk i Pulverform, *Jernkontorets Annaler*, 1951, vol. 135, pp. 89-115.

[3] S. Eketorp: Désulfuration par la Chaux Solide, *Revue de Metallurgie*, 1955, vol. 52, pp. 718-724.

[4] B. Kalling and S. Eketorp: Desulphurization of Pig Iron with Solid Lime, *Blast Furnace and Steel Plant*, 1957, vol. 45, pp. 494-497, 513.

[5] B. Trentini, L. Wahl, and M. Allard: Désulphuration de la Fonte par Insufflation de Poudre de Chaux, *Revue de Metallurgie*, 1936, vol. 53, pp. 388-399; *Journal of the Iron and Steel Institute*, 1956, vol. 183, pp. 124-134.

[6] R. I. Higgins and J. C Billington: Production of Low Phosphorus Foundry Iron from High Phosphorus Iron Ores, B.C.I.R.A. *Journal of Research and Development*, 1958, vol. 7, February, pp. 171-187.

[7] J. L. Harrison: Practical Aspects of Pretreatment Processes, *Journal of Iron and Steel Institute*, 1959, vol. 191, pp. 328-336.

[8] J. Sittard: Die Vorfrischanlage der Eisenwerkgesellschaft Maximilianshutte AG in Sulzbach-Rosenberg, *Stahl und Eisen*, 1956, vol. 76, pp. 1544-1561.

Magnetic Materials

by J. J. Becker, General Electric Co.

THE Fifth Annual Conference on Magnetism and Magnetic Materials, sponsored by the AIEE in cooperation with the American Physical Society, the IRE, The Metallurgical Society of AIME, and ONR took place Nov. 16-19 in Detroit. More than 150 scheduled papers plus several last-minute items were presented to over 800 registrants, including a number of contributions from distinguished foreign visitors. The size of this annual conference indicates the growth and importance of the field of magnetism and magnetic materials in present-day science and technology. There were sessions on spin waves, resonance, nuetron diffraction, oxides, garnets, magnetic salts, permanent magnets, soft materials, metals and alloys, anisotropy, thin films, computers, and techniques and devices. Some highlights of particular interest to metallurgists will be briefly reviewed here.

Permanent magnets

Fine-particle theory is now universally accepted as the basis for the interpretation of permanent magnet properties. This theory considers how particles of magnetic material can be so small that it is energetically unfavorable for them to contain magnetic domain boundaries, and indicates the sorts of properties that may be expected under these conditions. Not only is the theory being applied to the understanding of permanent-magnet precipitation alloys like Alnico, but it has also led to the development of processes for the direct production of fine particles, notably by electrodeposition into mercury. Paine and Luborsky presented a very interesting interpretation of the properties of Alnico in terms of structural units consisting of H-shaped groups of precipitate particles. Considerable interest was aroused by the announcement by several workers from Philips in the Netherlands of some preliminary results on fine particles of manganese-aluminum alloys containing around 75 at. pct Al. A metastable phase in this system has remarkable and potentially useful permanent-magnet properties. This material joins the ever-growing list of manganese's ferromagnetic alloys.

Soft magnetic materials and magnetic anisotropy

It has been known for many years that some iron-nickel and iron-nickel-cobalt alloys can be given a preferred direction of easy magnetization by heat treatment in a magnetic field, a procedure that does not produce any obvious changes in microstructure. The theory behind this effect has developed from considerations of the energies of unlike-atom pairs in the field of the local magnetization in the material. With an external field applied, at temperatures high enough for atom motion, these pairs would presumably align themselves parallel to the magnetization, which in turn is parallel to the applied field. However, this whole line of reasoning has been thrown open to serious question by experiments reported by Nesbitt, Heidenreich, and Williams. They found that the presence of oxygen is required in order for magnetic annealing to occur. In a 63 pct Ni-35 pct Fe-2 pct Mo alloy, for example, when they reduced the oxygen content to 6 ppm by hydrogen purification the material would not respond to magnetic annealing. But when they increased the oxygen content to 77 ppm the material showed its customary response to heat treatment in a magnetic field—that is it developed a magnetic easy direction in the direction of the applied field, as evidenced by a rectangular hysteresis loop in that direction and by torque measurements. The authors associate these effects with a faulted structure produced by the oxygen.

A number of papers dealt with the production of preferred orientations, particularly during secondary recrystallization. In many instances it now seems to be established that the selection of grains that grow the fastest during this process, when grain size becomes much greater than sheet thickness, is determined by the relative energy of the surfaces of grains in different orientations with respect to the plane of the sheet. As one might expect, the chemical nature of the atmosphere, as well as the temperature, becomes important in determining these relative energies. Some experiments by Kohler in which a specific texture became predominant and disappeared again as the H_2S content of the atmosphere was increased were interpreted on this basis.

Kouvel reviewed the recent work on exchange anisotropy in alloys. Exchange anisotropy involves the possibility of atomic magnetic moments being oriented either parallel or anti-parallel to each other within the crystal structure of the material. Under the proper conditions this can result in unsymmetrical hysteresis loops, even in materials that are magnetically unidirectional, so that the magnetization wants to point not just along a specific axis but down a specific direction. This extremely important effect was first discovered by Meiklejohn in partially oxidized fine particles of cobalt and has since been found in nickel-manganese, manganese-copper, and a number of other alloys.

Chikazumi discussed the magnetic anisotropy produced by light cold rolling of single crystals. This does not involve any recrystallization or other obvious structural changes but is associated with the slip occurring during rolling. In some materials the magnetic easy direction produced by this process is at right angles to the rolling direction. In the single crystals of Fe_3Al discussed by Chikazumi,

the magnetic easy direction is the same as the rolling direction. These effects are interpreted in terms of the formation or breakup of unlike-atom pairs by slip. The origin of this magnetic anisotropy is to be found in the number and orientation of such atom pairs, and this interpretation is thus closely akin to the current thinking about magnetic annealing. However, as pointed out above, this whole point of view on the magnetic annealing question now appears to be in serious difficulty as a result of experiments showing that oxygen is necessary for magnetic annealing. What bearing this has on rolling anisotropy is not yet known.

Thin films

One of the most active subjects in magnetism at present is the production and properties of thin films of ferromagnetic metals and alloys. *Thin* in this context usually means of the order of 1000 Å and the films are almost always deposited from the vapor. The reason for the intense interest is that their magnetization can be made to reverse extremely quickly, making the films highly attractive for use in digital computers. Basic research and development are running in parallel in this field. Thin films exhibit some new and puzzling phenomena that still need scientific explanation. Meanwhile, the chief problem plaguing those who attempt to make practical films for computer applications is their reproducibility. Without sufficient understanding of the relationship between structure and properties in the films, it appears that not all the variables involved in their production are under control. Thin films of any ferromagnetic material, including pure metals, invariably exhibit uni-axial magnetic anisotropy, regardless of the crystal structure of the parent metal. This anisotropy seems to come from two different sources; the first is that produced by the presence of a magnetic field during evaporation, giving an easy direction of magnetization in the film corresponding to the direction of the field applied during evaporation. This easy direction can be moved by heating the films slightly with the field in a new orientation. This seems quite analogous to the magnetic annealing phenomena discussed above, except that it happens in pure metals as well as alloy films, making the atom-pair approach untenable from the start. Since the presence of oxygen has been shown to be necessary in the bulk alloys, it is interesting to speculate that the mechanism may be the same in films. However, this has not yet been established experimentally.

Uniaxial magnetic anisotropy also occurs in films that are evaporated in such a way that the beam of metal vapor strikes the substrate at an angle to the perpendicular. In this case the magnetic easy direction is in the plane of the film and is perpendicular to the plane defined by the incident beam and the normal to the film. This effect can be fully as large as the magnetic field effect and perhaps larger. It does not appear to be due to preferred orientation of the grains in the film, but is associated with some sort of oriented structural irregularity whose nature is not yet understood in detail. The grain size in these evaporated films, incidentally, is extremely small, on the order of a few hundred Angstroms.

A measurement of fundamental importance was reported by C. A. Neugebauer, who measured the saturation magnetization of nickel films as a function of thickness down to a few Angstroms. It had been believed on the basis of earlier measurements that the saturation magnetization decreased with film thickness until it was zero at room temperature for 20 Å nickel films, an effect discussed theoretically in terms of numbers of near neighbors for ferromagnetic coupling. Neugebauer's measurements, made on very clean films in very high vacuum, indicate that this effect is not real and that ferromagnetic coupling can occur in very small numbers of atoms.

There were a great many more papers on many other aspects of magnetism and magnetic materials that are not reported here. The field is tremendously active and full of exciting developments, both scientific and technological. Attention is called to this year's meeting, which will be held in New York City, November 14-17.

Powder Metallurgy

by J. R. Van Orsdel, Battelle Memorial Institute

ADVANCES in the technology of continuous compacting of metal powders promises to create expanding markets for metal powders and reduced outlays for capital equipment in metal fabricating plants.

Fabrication of sheet and strip from metal powders is attractive to many fabricators because high yields are obtained. If the powder is no more costly than ingot material, the process can offer definite economic advantages.

Republic Steel Corp. has announced its new process for producing steel strip from iron ore without melting. In this process iron ore is highly purified and reduced to metallic iron powder. The iron powder is then fed between four rolls, where it is compressed into a semi-solid strip with sufficient green strength to hold together. The green strip is heated to 2200°F in a re-

ducing atmosphere to sinter-bond the iron powder. Hot rolling furthers the bonding processes and brings the strip to full density and the desired gage. Coils of steel from the hot-rolling mills go through the usual operations of pickling, cold rolling, and annealing before being recoiled or cut into sheets. Hot-rolled coils are said to have the same quality as conventionally made steels.

Further advancement in the art of powder compaction has been made by Westinghouse engineers. In their process a relatively inexpensive pressing technique produces sheets and bars of uniform density and unrestricted length. The technique consists of loading powder into a three-sided box die and compressing the powder in steps with a special punch. The punch has a flat pressing surface parallel to the powder surface and also a heel which is angled upward with respect to the powder suface. Thus, after each stroke of the press, the powder compact consists of a section which is flat and fully compacted followed by a section in which the compaction varies from the maximum value to zero. Therefore, by withdrawing the compact from the open fourth side of the die after each stroke, an amount which is less than the length of the horizontal surface of the punch, a continuous method of compaction is obtained.

Metal powders

National Research Corp. is now producing ultra-fine metal powders said to have an average particle size of 200 to 600Å. According to a communication in September, they are regularly producing aluminum, iron, nickel, copper, and other powders such as magnesium, silver, gold, lead, and zinc on special order basis. The extremely high surface energies and areas associated with such finely divided powders suggest a number of applications in the fields of chemistry, metallurgy, and electronics. Applications in powder metallurgy are of interest because of the particle size range. Mixtures of these ultra-fine powders should approach a homogeneity unattainable with powders of conventional size. Therefore, new properties might be obtained by mixing powders in proportions not ordinarily found in alloys.

Particle size determination

Metallurgists and ceramists are frequently confronted with the task of determining particle sizes and size distribution in powders. Microscopic counting, sieving, and various sedimentation techniques are frequently used. However, these methods are often quite tedious, and more rapid and accurate methods have been sought. Recently, the Process Control Services Co. of Elmhurst, Ill., marketed the Coulter Counter, which is described as an electronic device capable of counting and sizing sub-sieve particles in the size range of ½ to 200 μ at a rate of 6000 per sec. The method determines the number and size of particles in an electrically conductive liquid via the Coulter principle. This is done by forcing a liquid suspension of the powders to flow through a small aperture having an immersed electrode on each side of the aperture. The flow of current through the aperture is a function of the aperture size and the resistance of the suspending medium. As each particle passes through the aperture, it replaces its own volume of electrolyte within the aperture, momentarily changing the resistance value between the electrodes. This produces a pulse of short duration having a magnitude proportional to particle volume. The resulting series of pulses is electronically amplified, scaled, and counted. Powdered metals behave as nonconductors due to the oxide film on particle surfaces. Electrical charges on the particles have no apparent effect.[1]

Some materials that have been successfully evaluated by the apparatus are: tungsten, iron oxide, aluminum, silicon metal, beryllium, silver, zinc, tantalum, titanium, tantalum oxide, ferromagnetic metals, and silver oxide.

Bonding carbides to steel

Plymet, a new powder metallurgy product used to bond carbides to steel, is being produced by Powder Alloys Corp., Clifton, N. J. This material is supplied in wafer form about 1/32-in. thick.

Plymet is produced from a metal powder mixture, and is subjected to a low-temperature sintering operation. High-temperature brazing or welding flux is usually admixed with the metal powders. In the bonding operation, a Plymet wafer slightly larger than the carbide tip is placed between the carbide and the steel shank, and the assembly subjected to a pressure of about 500 psi. Pressure is maintained while the joint is heated to a temperature of 1900° to 2000°F. A holding time of only 30 sec to 1 min at temperature is required. During the heating cycle, flux oozes out of the pores and coats the joints. The portion of the wafer covered by the carbide and thus subjected to the pressure compresses about 15 to 20 pct in thickness, eliminating most of the voids and resulting in a joining metal hardness of about R_c 45. Excess Plymet outside the carbide is not compressed and remains soft and friable, which makes it easy to remove by filing or sanding. Unlike brazing, the Plymet does not melt during the bonding operation. The powder mixture is such that a low expansion iron-nickel alloy similar to Invar results.

Even though time, temperature, and pressure of bonding are of low magnitude, surprisingly complete diffusion of the metal powders in the wafer takes place, as well as bonding at the two interfaces of carbide to Plymet to steel.[2]

Pressing lubricants

Substituting lithium stearate for the zinc stearate conventionally used for pressing lubricant in 70-30 brass compacts has been shown to give substantially higher properties in the sintered product. Higher sintered densities and more complete spheroidization of porosity were the major contributing factors for the improved properties. The best properties were obtained with a lithium stearate addition of 0.50 to 0.75 pct, a compacting pressure of 50 tsi, and a sintering atmosphere of nitrogen at 1600° to 1625°F. The 70-30 brass compacts lubricated with lithium stearate and sintered in nitrogen had a 37 pct higher tensile strength and 164 pct greater elongation than those compacts lubricated with zinc stearate and sintered in hydrogen. Densities were 94.5 to 95.0 pct and 85 to 89 pct respectively.[3]

References

[1] R. H. Berg: Preprint of paper No. 4, Session 39, ASTM Meeting, June 27, 1958.

[2] J. F. Kuzmick and G. B. Goodfellow: *Use of Powder Metallurgy for Diffusion Bonding of Cemented Carbide to Steel*, Fifteenth Annual Meeting, Metal Powder Industries Federation.

[3] F. J. Zaleski and R. A. Powell: *The Effects of Lithium Stearate Additions and Various Atmospheres on Sintered Brass Compacts*, Fifteenth Annual Meeting, Metal Powder Industries Federation.

Powder Metallurgy Newsletter Available; June Meeting Discussed

The AIME Powder Metallurgy Committee Newsletter is now available. The Newsletter is issued without charge to members of AIME upon request to The Metallurgical Society. It is available to non-members for $2 per year. Issued five times a year by the Institute of Metals Division's Powder Metallurgy Committee, the Newsletter is edited by Henry H. Hausner.

Each issue covers complete activities in powder metallurgy. The International Powder Metallurgy Conference coming up June 13-15 at the Hotel Biltmore in New York is perhaps the biggest news in the area. At least 30 papers from internationally-known powder metallurgists are anticipated. But there is still room for original contributions of merit which are as yet unpublished. Abstracts should be addressed to *Claus G. Goetzel, Metallurgical Engineering Dept., New York University, University Heights, New York 53, N. Y.*

THE SENIOR CLASS:

Metallurgy and Metallurgical Engineering

by John P. Nielsen

THIS is the second year of publication of the list of seniors in metallurgy and metallurgical engineering throughout the various engineering and science schools in the US. This year the number is 696 in 52 schools, or a drop of 56 seniors from last year.

These seniors include those specializing in extractive metallurgy, metallurgical engineering, materials engineering, physical metallurgy, metal science, and metal physics. They exclude mining and mineral beneficiation engineers, geologists, ceramic and plastic's engineers. The latter group will be found in a corresponding list published in MINING ENGINEERING.

Lest there be any confusion, it should be noted these are seniors from the various schools, as of October 15, 1959, and the lists will not necessarily correspond to the list of graduates in June. In a number of cases the potential graduates of February and June are listed separately. Also, there are schools that graduate classes as late as August.

JOHN P. NIELSEN is professor and chairman, Dept. of Metallurgical Engineering, New York University. Data for this article were obtained under the auspices of the AIME Student Affairs Committee, John C. Calhoun, Jr., John R. Van Pelt, Jr., and John P. Nielsen (Chairman).

UNIVERSITY OF ALABAMA, University, Ala., Dept. of Metallurgical Engineering, Prof. E. C. Wright, Chm. Seniors: Feb., 1960: J. E. Battles (June) T. T. Bales, L. D. Gaynor, E. R. Heaton, C. R. Kellerman, H. L. McKeon, W. R. Nettles, H. B. Legrone.

UNIVERSITY OF ALASKA, College, Alas., School of Mines, Earl H. Beistline, Dean. Seniors: NO SENIORS, 1959-60.

UNIVERSITY OF ARIZONA, Tucson, Ariz., College of Mines, Dept. of Mining and Metallurgical Engineering, Prof. T. M. Morris, Head. Seniors: C. L. Anderson, **L. Branin, C. W. Field, W. Greer, S. Hightower, J. Howell,** R. Kirby, B. Natta, **J. A. Powell,** R. Richey, **W. Seginski,** J. Stokes, T. J. Tomko, L. I. Van Torne, **S. Zalsman.**

POLYTECHNIC INSTITUTE OF BROOKLYN, New York, N. Y., Dept. of Mechanical Engineering, Prof. Charles T. Oergel, Head. Seniors: **P. Baumgartner,** N. Borntsein, A. Filippi, G. R. Kotler, P. Lane, J. Lanzafame, **F. Longo,** K. Orlowsky, **R. R. Richardson,** C. D. Schaper, E. Schecter, **H. Schwind.**

UNIVERSITY OF CALIFORNIA, Berkeley, Calif., Dept. of Mineral Technology, Prof. Joseph A. Pask, Chm. Seniors: A. P. Cohen, **M. J. Davis,** L. C. Erickson, G. A. Garies, D. Green, W. Haley, W. K. Halnan, W. L. Price, D. A. Sullivan, D. N. Wiele.

CARNEGIE INSTITUTE OF TECHNOLOGY, Pittsburgh, Dept. of Metallurgical Engineering, Prof. C. L. McCabe, Head. Seniors: **L. M. Adelsberg,** D. A. Arnone, S. N. Begg, J. F. Beisler, A. Blaskovich, R. K. Burkett, J. M. Clayton, F. M. Danowski, J. D. Defilippi, E. G. Dubrawka **A. U. Ernas,** N. Fiore, G. Friedman, M. T. Galuschak, **R. Gibala,** L. M. Glumac, C. D. Green, R. R. Hilsen, R. J. Knoth, D. F. Latwon, G. D. Levine, **C. Long,** E. A. Mizikar, **P. Panchal,** W. F. Riesmeyer, C. E. Rowden, J. F. Rzepka, S. H. Skalka, **R. C. Svedberg,** R. L. Szuch, J. J. Welsh, T. Wilson.

CASE INSTITUTE OF TECHNOLOGY, Cleveland, Ohio, Dept. of Metallurgical Engineering, Professor Alexander R. Troiano, Chm. Seniors: R. Anderson, J. A. Bako, R. S. Bell, T. H. Bishop, **R. W. Breitzig,** H. I. Burrier, H. E. Cook, L. C. Cosentino, C. J. Dascoli, P. M. Evanski, T. A. Free, J. W. Frye, W. D. Huskonen, I. Jekkals, R. B. Minch, T. A. Mulvihill, W. E. Norem, G. L. Orenstein, J. A. Pocza, R. L. Randall, C. I. Rosner, W. P. Ross, J. H. Rudge, R. R. Seeley, B. A. Sokol, R. C. Stephens, L. I. Toriello, A. Tyler, C. Weiner, M. B. Whiteman.

UNIVERSITY OF CINCINNATI, Cincinnati, Ohio, Dept. of Chemical and Metallurgical Engineering, Prof. William Licht, Head. Seniors: W. Black, J. J. English, R. H. Ernst, J. R. Freeman, D. W. Horton, D. H. Kah, W. L. Lee, K. R. Lehr, G. D. Lloyd,

R. E. Mintus, C. O. Moeser, D. F. Schomaker, W. C. Seward, D. Swanson, J. R. Thompson, Jr.

COLORADO SCHOOL OF MINES, Golden, Colo., Dept. of Metallurgical Engineering, Prof. H. Gordon Poole, Head. Seniors: **Boyd, B. K., Cederstrom, R. R.,** Daniele, R. A., Dugger, A. L., Engel, I. W., Green, J. F., Jr., Heister, S. B., Hoagland, G. W., Hoffman, R. B., **Judy, M. M.,** Kane, G. C., **Karlsson, R. H.,** Langher, F. S., Lindroth, G. A., Meltzer, L. H., Miley, D. V., Miller, A. E., Morse, D. W., Myers, T. L., O'Neil, D. B., Po Saw, T. O., Prescott, R. A., Pribila, L. W., Jr., Sargent, M. R., Severns, R. R., **Shier, G. D.,** Turner, A. S., Walton, G. A., West, M. L., Jr.

COLUMBIA UNIVERSITY, New York, N. Y., Dept. of Mining, Metallurgical and Mineral Engineering, Prof. M. D. Hassialis, Chm. Seniors: J. Ahn. I. M. Bernstein, T. E. Daranyi, M. E. Rosenblum, W. F. Schnabel, H. K. Shen.

CORNELL UNIVERSITY, Ithaca, N. Y., School of Chemical and Metallurgical Engineering, Prof. C. C. Winding, Dir. Seniors: **J. H. Finnegen,** H. F. Kaiser, Jr.

DREXEL INSTITUTE OF TECHNOLOGY, Philadelphia, Pa., Dept. of Metallurgical Engineering, Prof. A. W. Grosvenor, Head. Seniors: F. P. Altimore, J. R. Cauvin, J. L. Cavallaro, W. V. Coll Jr., H. E. Collins, J. L. Godshall, P. O. Hagarman, R. S. Klein, V. Klein, G. Krywusha, G. A. Kurisky, M. I. Lewis, W. A. Mannschreck, R. R. Martino, M. Raefsky, **W. Schuele,** R. F. Zierow.

UNIVERSITY OF IDAHO, Moscow, Idaho, College of Mines, Dept. of Mining and Metallurgy, Prof. Joseph Newton, Head. Seniors: D. W. Duggan, D. S. Durham, D. G. Hargreaves, W. L. Orton.

UNIVERSITY OF ILLINOIS, Urbana, Ill., Dept. of Mining and Metallurgical Engineering, Prof. Thomas A. Read, Head. Seniors: (February 1960) **C. R. Casey, C. Godfrey,** M. Hyman, B. G. Koepke, G. Schauner, D. F. Tower, (June 1960) A. Bonfiglio, M. Coleman, T. R. Drews, T. Dreyer, T. Follensbee, **M. Garza,** G. A. Gegel, F. L. Krempski, R. J. Larsen, G. Mah, E. A. Mattick, D. L. Stoltz, J. G. Yadron.

ILLINOIS INSTITUTE OF TECHNOLOGY, Chicago, Ill., Dept. of Metallurgical Engineering, Prof. L. F. Mondolfo. Chm. Seniors: **D. C. Brillhart,** G. P. Coker, J. G. Dooman, P. Fleissig, J. E. Henry.

UNIVERSITY OF KANSAS, Lawrence, Kan., Dept. of Mining and Metallurgical Engineering, Prof. K. E. Rose, Chm. Seniors: M. E. Bukaty, C. F. Gibbon, F. G. Hodge, A. A. Popoff, G. D. Richardson, K. B. Yeo, W. R. Young.

UNIVERSITY OF KENTUCKY, Lexington, Ky., College of Engineering, Dept. of Mining and Metallurgical Engineering, Prof. Richard S. Mateer, Head. Seniors: (Feb. 1960) A. J. Greif, G. R. Wallace, (June, 1960) C. R. Dixon, Jr., **J. R. Perkins,** J. E. Steedly, Jr., L. S. Wu.

LAFAYETTE COLLEGE, Easton, Pa., Dept., of Metallurgical Engineering, Prof. Leon J. McGeady, Head. Seniors: J. R. Amato, R. E. Jemison, N. G. Koopman, K. J. Kundig, H. S. Kim, C. M. Lee, Jr., G. P. Noble, W. M. Triggs.

LEHIGH UNIVERSITY, Bethlehem, Pa., Dept. of Metallurgical Engineering, Prof. Robert D. Stout, Head. Seniors: J. W. Barton, M. G. Bleiler, C. R. Borland, C. V. Bostrom, R. T. Brenna, H. F. Brooks, E. R. Buchanan, R. R. Crawford, R. O. Donaldson, G. L. Fisher, J. Gard, J. G. Gensure, D. H. Lewis, M. J. McNamara, D. J. Nesslage, M. R. Notis, T. R. Richards, D. A. Rissmiller, W. J. Richardson, **R. O. Scattergood,** B. D. Schafebook, S. E. Siuciak, H. W. Stemme, R. H. Sterne, C. A. Stitt, J. R. Stoneburner, D. M. Weaver.

UNIVERSITY OF MARYLAND, College Park, Md., College of Engineering, Metallurgy Program, Prof. William A. Pennington, Head. Seniors: S. C. Manaktala, L. D. Norman, Jr., W. E. Nuttall, H. T. Yolken.

UNIVERSITY OF MASSACHUSETTS, Amherst, Mass., Materials and Metallurgical Engineering, Prof. Carl A. Keyser, in charge. (Senior thesis in metallurgy degree designation in another field.) Seniors: D. A. Campbell, C. B. Knight, R. I. MacNayr, J. W. Miner, D. R. Muzyka, D. W. Pearsall.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Cambridge, Mass., Dept. of Metallurgy Prof. John Chipman, Head; Seniors: T. H. Ansbacher, A. J. Ardell, T. F. Bower, H. D. Brody, T. H. Courtney, J. Goldstein, J. I. Goldstein, **S. R. Goodman,** W. H. Goodnow, H. W. Hayden, Jr., N. C. Hicks, R. J. Higgins, H. A. Hobbs, Jr., G. S. Irons, P. D. Jacobson, D. Kalish, S. J. Michalik, E. P. Montrone, M. A. Moreno, H. Morrow, III, G. A. Miller, F. B. Nagel, J. R. Palmieri, C. M. Pierce, E. R. Pollard, Jr., M. D. Reed, T. A. Remmers, L. D. Schmer, Susan E. Schur, M. A. Schuster, D. J. Sipos, G. D. Slaweclci, R. S. Voog, **R. A. Walsh,** I. L. Weinman, J. M. Woodall.

MICHIGAN COLLEGE OF MINING AND TECHNOLOGY, Houghton, Mich., Dept. of Metallurgical Engineering, Dr. R. L. Smith, Head; Seniors: D. C. Augustine, E. C. Bogren, W. G. Carmody, **M. M. Cho,** C. D. DesRosier, **G. M. Dorland,** W. J. Duca, R. J. Filar, **D. C. Fleming,** R. G. Grates, **R. O. Harma,** J. M. Khoury, W. A. Knable, J. P. McKay, W. W. Maki, E. L. Michaels, W. M. Nicola, E. W. Olson, T. C. Pechauer, J. A. Penkivich, J. A. Petrusha, R. E. Predmore, A. L. Rafalski, R. H. Richards, F. M. St. John, E. J. Samuelli, D. J. Scelonge, C. S. Schack, **G. J. Scott,** R. H. Smart, G. E. Tardiff, K. H. Utzat, **V. A. Vellella, R. E. Warnock, R. A. Wickman,** L. S. Willett, C. R. Willam, **D. D. Wilson,** J. J. Wisniewski, M. W. Wisti, C. H. Zatsick.

UNIVERSITY OF MICHIGAN, Ann Arbor, Mich., Dept. of Chemical and Metallurgical Engineering, Prof. Donald L. Katz, Chm. Seniors: B. L. Beach, L. A. Bloomeld, G. D. Briceno, E. Byrnes, E. A. Frutig, R. L. Greene, V. E. Grinnell, R. D. Homeyer, **F. D. Lemkey,** E. A. Merriman, **R. J. Parizek, A. M. Patterson,** P. A. Patterson, R. P. Pitsch, **J. C. Sarace,** J. W. Smythe, D. L. Truex.

MICHIGAN STATE UNIVERSITY, E. Lansing, Mich., Dept. of Metallurgical Engineering, Prof. A. J. Smith, Chm. Seniors: S. J. Archer, T. F. Berry, C. K. Chyung, J. R. Eagan, G. W. Deffendall, T. J. Herrmann, T. A. Holz, P. Y. Ip, A. F. Marchant, H. G. Richter, D. P. Slater, R. E. Wilson.

UNIVERSITY OF MINNESOTA, Minneapolis, Minn., Dept. of Metallurgy, Prof. Morris E. Nicholson, Head, Dept. of Metallurgical Engineering, Prof. Strathmore, R. B. Cooke, Head. Seniors: D. M. Berndt, L. Bonicatto, **W. B. Crouch, G. E. Gruenhagen,** D. R. Ireland, R. Kielty, **H. G. Posthuma, R. M. Stoss, A. D. Taylor.**

MISSOURI SCHOOL OF MINES AND METALLURGY, Rolla, Mo., Dept of Metallurgical Engineering, Prof. A. W. Schlechten, Chm. Seniors: (January) D. C. Bartosik, K. A. Batubara, D. G. Cooper, D. A. Dallmer, R. O. Dean, V. R. Groner, G. W. King, M. W. Loket, J. L. Nagy, M. A. Padilla, D. E. Price, S. H. Pru, B. R. Smith, E. O. Speidel, J. P. Stewart, D. C. Stih, M. M. Tilman, **L. S. Todd, R. J. Urban, Jr., G. Urdaneta,** E. B. Williams. (June) **C. Akmakjian, J. M. Alyea,** W. Amidei, D. W. Anderson, **F. D. Anderson,** S. Bartlett, **T. D. Bates, J. O. Bloodsworth,** R. A. Booth, P. M. Borsenberger, B. L. Bramfitt, R. H. Brockelman, J. L. Cadden, W. J. Collins, C. A. Faunce, P. A. Finn, R L. Fisher, R. A. Fitzgerald, L. A. Flanigan, V. R. Groner, W. A. Henning, W. Holman, J. T. Hughes, **J. P. Kemper, K. E. King,** J. C. Lewis, G. J. Lukowitz, **H. J. Meyer,** G. J. Murphy, C. Parkash, R. A. Parker, K. I. Pendleton, W. F. Priesemeyer, D. L. Pulliam, H. M. Ray, R. P. Skow, R. A. Smith, J. D. Spagnola, E. T. Stark, E. H. Stewart, **G. I. Swartz,** F. W. Thielson, **C. A. Vansant,** N. T. Wagenheim.

MONTANA SCHOOL OF MINES, Butte, Mont., Dept. of Metallurgy, Prof. Vernon Griffiths, Head. Seniors: (February 1960) L. S. Greely. (June

1960) A. C. Bigley, Jr., J. C. Bjeletich, **W. R. Byrne,** W. Cronin, **J. Donovan,** E. J. Nicholson, **J. E. Thompson,** G. A. Grandy, (Min. Dress. Opt.)

UNIVERSITY OF NEVADA, Reno, Nev., Mackay School of Mines, Dept. of Metallurgy, Prof. J. S. Winston, Chm. Seniors: (February, 1960) **R. L. Landingham.** (June, 1960) W. L. Clarke, Jr., B. A. Condie, D. A. Jones, **H. C. Newman, R. C. Schenk.**

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY, Socorro, N. M., Dept. of Mining and Metallurgy. Prof. Frank W. Bowdish, Head. Seniors: **R. T. Borys,** W. Huenergardt, Jr., J. J. Pulaski, R. E. Staub, Jr.

NEW YORK UNIVERSTIY, New York, N. Y. Dept. of Metallurgical Engineering. Prof. J. P. Nielsen, Chm. Seniors: J. C. Bilello, **A. J. Goldman,** H. Ocken, W. Kern, **M. B. Rubinfeld, D. Seidman,** A. J. Steiner.

UNIVERSITY OF NORTH DAKOTA, Grand Forks, N. D., Dept. of Mining Engineering, Prof. A. W. Koth, Head. Seniors: No seniors 1959-60.

NORTHWESTERN UNIVERSITY, Evanston, Ill., Dept. of Metallurgy and Materials Science, Prof. Morris E. Fine, Chm. Seniors: F. T. Wimmer

UNIVERSITY OF NOTRE DAME, South Bend, Ind., DeDpt. of Metallurgical Engineering, Prof. E. A. Peretti, Head. Seniors: J. L. Cruse, R. J. Diersing, T. J. Fitzgerald, T. E. Kowalski, J. I. Long, C. A. MacMillan, R. F. Schossler, R. L. Stegman.

OHIO STATE UNIVERSITY, Columbus, Ohio, Dept. of Metallurgical Engineering, Prof. Mars G. Fontana, Chm. Seniors: R. A. Bishel, T. J. Bruce, J. A. Clum, W. T. Ebihara, E. J. Grandy, M. Kangilaski, R. L. Kennard, J. T. Lundin, H. A. Matlin, R. D. Orkin, P. S. Whipple.

THE UNIVERSITY OF OKLAHOMA, Norman, Okla, School of Metallurgical Engineering, Prof. W. R. Upthegrove, Chm. Seniors: (February,) **A. B. Sorkin.** (June,) C. Fagin, J. E. Irvin, D. R. Kane, R. D. Poirier.

UNIVERSITY OF PENNSYLVANIA, Philadelphia, Pa., School of Metallurgical Engineering, Prof. Robert Maddin, Dir. Seniors: E. J. Arndt, R. D. Fisher, 3rd, M. J. Ginsberg

THE PENNSYLVANIA STATE UNIVERSITY, University Park, Pa., College of Mineral Industries, Dept. of Metallurgy, Prof. Amos J. Shaler, Head. Seniors: T. M. Barnes, R. B. Batdorf, R. R. Brown, J. L. Clupper, J. F. Crouse, D. E. Horan, L. S. Janus, G. H. Karchner, J. W. Kocerha, D. M. Koncsics, J. A. Langus, R. L. McCarron, **J. A. Miller,** A. C. Nyce, T. R. O'Connell, G. F. Pauline, J. J. Pepin, H. V. Petersen, R. J. Roy, D. R. Rubash, J. J. Selko, G. K. White, R. J. Yinger.

UNIVERSITY OF PITTSBURGH, Pittsburgh, Pa., Dept. of Metallurgical Engineering, Prof. J. A. Berger, Chm. Seniors: L. A. Comunale, R. R. Corle, H. H. Cornell, C. S. Degrosky, J. B. Englert, L. E. Fischer, C. L. Hackett, F. J. Hann, P. Hatzimbes, G. E. Hicho, H. E. Horner, R. W. Hostinak, D. P. Kelly, C. B. Moesta, P. M. Radvansky, A. J. Ragan, D. J. Seman, E. R. Suveges, L. Timmeney, L. Tolchinsky, A. E. Tyburski, D. H. Yates.

PURDUE UNIVERSITY, Lafayette, Ind., School of Metallurgical Engineering, Prof. Reinhardt Schuhmann, Jr., Head Seniors: (February) **J. W. Castor,** D. F. Evans, H. W. Habart, **R. J. Russell, J. T. Venard,** W. L. Watson (June) C. E. Anderson, R. B. Berg, G. E. Darda, A. Gacic, P. L. Hudson, J. E. Pavlick, J. J. Rechtien, **T. Siamas,** L. J. Smith, L. A. Swanson

RENSSELAER POLYTECHNIC INSTITUTE, Troy, N. Y., Dept. of Metallurgical Engineering, Prof. Arthur A. Burr, Head. Seniors: (Jan.) S. R. Rothstein (June) S. J. Acello, D. J. Alter, P. E. Arnold, T. R. Baruch, R. D. Betts, W. C. Blanchfield, R. A. Bollman, H. D. Braun, D. B. Butrymowicz, D. Duhl, L. P. Earvolino, J. W. Ellisber, A. Enis, J. F. Fogliano, W. P. Foley, Jr., C. J. Gaffoglio, B. M. Glasgal, S. J. Glick, E. N. Guleserian, D. I. Hoviss, R. F. Hyserman, B. A. Konrad, J. P. Kwolek, J. L. Matthews, W. E. Mayott, J. E. McDonald, J. B. McKeone, W. A. Moore, B. R. Newmark, C. J. Pellegrini, J. S. Pratt, S. I. Radnich, Jr., D. P. Susman, G. F. Taylor, Jr.

SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY, Rapid City, S. D., Dept. of Metallurgy, Prof. Paul H. Anderson, Head. Seniors: (February) **R. Mehle.** (June) **E. J. Bane,** C. T. Gorder, **J. C. Groen, J. R. Hancock, D. D. Hays, T. J. Hughes,** K. D. Hydinger, **D. R. Olson, C. Sterkel.**

STANFORD UNIVERSITY, Stanford, Calif., Dept. of Metallurgical Engineering, Prof. O. Cutler Shepard, Head. Seniors: **R. J. Austin,** T. W. Barnee, Jr., John E. Bond, William D. Kehr, W. K. McDonald, R. A. Reynolds, J. L. Robbins, E. A. Silva, R. E. Thompson

STEVENS INSTITUTE OF TECHNOLOGY, Hoboken, N. J., Dept. of Metallurgy, Prof. Alfred Bornemann, Chm. Seniors: (Senior electives in metallurgy, degree of engineering) W. Ardrey, D. Cluett, E. Concha, E. Dalton, J. Dalton, E. Davis, G. Demas, C. DiMartini, A. Edwards, G. Harper, M. Hersh, R. Kaul, R. Kline, R. Knolker, E. McWhiney, W. Marx, H. Morris, J. Pasquale, W. E. Smith.

TEXAS WESTERN COLLEGE, El Paso, Tex., Dept. of Mining and Metallurgy, Prof. J. C. Rintelen, Jr., Chm. Seniors: **N. C. Cook,** A. Correa-Nunez, **E. Escalante, G. L. Faulkner,** C. Fulton, M. E. Giono, F. Gee-Way Hsu, E. G. Kurkas, E. M. Pratt, **P. D. Watson**

UNIVERSITY OF UTAH, Salt Lake City, Utah, Dept. of Metallurgical Engineering, Prof. Milton E. Wadsworth, Head. Seniors: C. R. Brinkman, **J. N. Gardner,** T. F. Moss, D. D. Tuft, M. L. Robinson, D. I. Phalen, **J. R. Suazo**

VIRGINIA POLYTECHNIC INSTITUTE, Blacksburg, Va., Dept. of Metallurgical Engineering, Prof. John F. Eckel, Chm. Seniors: (December, 1959) R. H. Canada. (June, 1960) J. R. Alexander, C. P. Blankenship, D. P. Buchanan, R. G. Connell, Jr., C. Jason Corning, **T. G. Digges, Jr.,** B. N. Ferry, R. V. Lawrence, M. R. Louthan, Jr., R. W. Ogershok, E. Soucek, **E. A. Starke, Jr.,** A. H. Watkins, S. M. Wolf.

UNIVERSITY OF WASHINGTON, Seattle, Wash., School of Mineral Engineering, Metallurgical Engineering Div., Prof. Earl C. Roberts, Head. Seniors: (March) **L. F. Nelson,** E. B. Schwenk (June) F. M. Adams, D. E. Austin, D. C. Engdahl, L. E. McKnight, R. H. Olsen, R. Pellegrini, W. K. Sennott, N. A. Speed, J. M. Uchida, C. M. Walter, R. P. Williams

WASHINGTON STATE UNIVERSITY, Pullman, Wash., College of Engineering and Mineral Technology, Dept. of Metallurgy, Prof. S. A. Duran, Chm. Seniors: **W. L. Johnson,** D. W. McKinley, H. W. Miller, H. G. Nelson, J. D. Pierson.

WAYNE STATE UNIVERSITY, Detroit 2, Mich., Dept. of Chemical and Metallurgical Engineering, Prof. H. G. Donnelly, Head. Seniors: (January) B. G. Calfin, R. W. Patterson, **C. F. Rerat,** H. C. Rezeau, J. P. Titran, **R. H. Titran.** (June) J. F. Clark, T. Gottlieb, H. M. Ledbetter, Jr., L. B. Moorman, A. E. Schneider, **E. H. Ulin.**

WEST VIRGINIA UNIVERSITY, Norgantown, W. Va., Dept. of Chemical Engineering, Prof. H. P. Simons, Head Seniors: No Seniors in metallurgy for 1960.

UNIVERSITY OF WISCONSIN, Madison, Wis., Dept. of Mining and Metallurgy, Prof. P. C. Rosenthal, Chmn. (January 1960) Seniors: H. T. Bolte, Jr., R. Guhl, Jr., T. W. Mueller, R. R. Sexton, (June 1960) L. E. Abrahamson, W. D. Bowers, **D. M. Denniston,** G. L. Dubberstein, H. J. Kamps, P. H. Meyst, D. R. Nelson, W. J. Payne, **V. Petrovich,** R. H. Pfau, **E. M. Pilarski,** T. A. Richter, T. A. Roth, **J. A. Schroeder, J. M. Svoboda,** T. J. Wissing, **A. Zjaba.**

YALE UNIVERSITY, New Haven, Conn., Dept. of Metallurgy, Prof. W. D. Robertson, Ch. Seniors: H. R. Baumgartner, **D. P. Stuhr.**

CHECK THESE DATES FOR 1960

Feb. 14-18

AIME
Annual Meeting;
New York,
Sheraton-Atlantic
and Statler Hilton
Hotels

Apr. 4-6

Blast Furnace
Conference;
Chicago,
Palmer House

Apr. 4-6

Open Hearth
Conference;
Chicago,
Palmer House

May 25-26

Conference on
Refractory
Materials
and Alloys;
Detroit,
Wayne State
University

Important Metallurgical Society Conferences

June 9-10

Symposium on
Metallurgy
of Columbium;
Bolton Landing,
N. Y.,
Hotel Sagamor

June 13-15

International
Powder Metallurgy
Conference;
New York,
Hotel Biltmore

July 11-12

Conference on
Response of
Materials to
High-Velocity
Deformation;
Estes Park, Colo.

Aug 29-31

Semiconductors
Conference;
Boston,
Statler Hilton
Hotel

Oct. 17-21

Fall Meeting
of The Metallurgical
Society;
Philadelphia,
Hotel Sheraton

Nov. 30-Dec. 2

Electric Furnace
Conference;
Chicago,
Morrison Hotel

Remember These Dates For AIME Regional Conferences

Apr. 21-22

Southwest
Metals and
Minerals
Conference;
Los Angeles,
Ambassador Hotel

Apr. 28-29

Pacific
Northwest
Metals and
Minerals Conference
Portland, Ore.,
Sheraton Hotel

May 26-27

New England
Regional
Conference;
Boston,
Statler Hotel

Oct. 5-7

Rocky Mountain
Minerals
Conference;
Salt Lake City,
Newhouse Hotel

. . . And These Other Meetings

Nuclear Congress,
Apr. 3-8, 1960;
New York,
The Coliseum

To Keep in Mind: International Symposium on Agglomeration, **Apr. 14-16, 1961;** Philadelphia, Sheraton Hotel

Conference on
Magnetism and
Magnetic Materials,
Nov. 14-17,
New York

AIME OFFICERS:
PRESIDENT—HOWARD C. PYLE
PAST-PRESIDENT—AUGUSTUS B. KINZEL
PRESIDENT-ELECT—JOSEPH L. GILLSON
VICE-PRESIDENTS—E. C. BASSON, THOMAS C. FRICK, WALTER R. HIBBARD, JR., ELMER A. JONES, JOHN C. KINNEAR JR., ROGER V. PIERCE
TREASURER—C. R. DODSON
SECRETARY—ERNEST KIRKENDALL
AIME STAFF:
ASST. SECRETARIES—J. B. ALFORD, H. N. APPLETON, J. C. FOX, R. W. SHEARMAN
ASST. TREASURER—JOHN LYNCH

AIME NEWS

Flat Rolled Products Conference on Jan. 20

A note of reminder that the second conference on Flat Rolled Products (semi-finished and finished) is coming up Jan. 20th at the Hotel Del Prado, Chicago. The Mechnical Working Committee, Iron and Steel Division of The Metallurgical Society, is sponsoring the event in co-operation with the Chicago section, AIME. Registration is from 6:00 to 9:00 pm on Tuesday, Jan. 19th. See p. 850 of the December issue for the full conference program.

Proceedings of the first conference have recently been issued as the first of a series of books on technical conferences sponsored by The Metallurgical Society.

Flat Rolled Products: Rolling and Treatment is offered to AIME members at $3; non-members, $3.75. Members should order through The Metallurgical Society, 29 W. 39th St., New York 18. Non-members should order directly from Interscience Publishers Inc., 250 Fifth Ave., New York 1.

Columbium Symposium Abstracts Due Feb. 1

Feb. 1st is the deadline for submission of abstracts for the Columbium Metallurgy Symposium to be held June 9-10 at Hotel Sagamore, Lake George, N. Y.

David L. Douglass, Symposium Chairman, is accepting abstracts. Address Dr. Douglass at Knolls Atomic Power Laboratory, General Electric Co., Schenectady, N. Y.

Hudson-Mohawk section of AIME is sponsoring the conference. Papers on the mechanical properties, fabrication, corrosion and oxidation, and the general physical metallurgy of columbium are anticipated.

International Symposium on Cu, Ni, Co Slated by EMD at Annual Meeting

The International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt to be held during the Annual Meeting promises to make a significant contribution to metallurgical knowledge.

Papers from Belgium, Canada, Chile, France, Northern Rhodesia, Southern Rhodesia, Sweden, in addition to the US, will be presented during the four days of sessions.

The Symposium will get underway on Monday afternoon, with the first of six technical sessions beginning at 2:30 pm. This initial session will be of a general nature, with succeeding meetings specializing in particular aspects of copper, nickel, and cobalt.

On Tuesday morning there is a session on Fuel-Fired Smelting and Converting. The EMD Annual Dinner that night gives pause before tackling the session on Electric Furnace Smelting on Wednesday morning. That afternoon will see an examination of Atmospheric and Elevated Pressure Leaching. On Thursday, the final day of the Annual Meeting, comes another event, the EMD Annual Lecture, this year by Charles R. Kuzell, Phelps Dodge Corp. Closing out the Symposium will be a technical session on Refining.

Accomplishment of this unique presentation did not come without much planning. Credit is due Paul Queneau, Chairman of the Symposium Committee. Assisting him were vice chairman W. L. Lennemann, A. C. Richardson, R. J. Stevens, and J. L. Wyatt. Committee members included F. R. Archibald, Howard Barkell, J. B. Clemmer, R. C. Hills, F. L. Holdereed, H. H. Kellogg, L. M. Pidgeon, J. H. Schloen, R. Schuhmann, Jr., and M. E. Wadsworth.

'58 Electric Furnace Volume Out; 15-year Index Also Available

Electric Furnace Steel Proceedings, 1958, has just been issued. This record of the 16th Annual Electric Furnace Conference, held in Detroit Dec. 3-5, 1958, includes both papers presented and transcripts of discussions. The meeting in the motor city enabled men of the auto industry and electric furnace group to resolve some of their common problems. It also marked the emergence of the Special Arc Group as a third division of the Electric Furnace Committee.

Registrants at the 1958 Conference will automatically receive their copies free. Others who wish to order it may do so by addressing the Order Dept., AIME, 29 W. 39th St., New York 18. Price of the volume is $7 for members; $10 for non-members.

Registrants for 1958 are also in for a bonus. The 15-year index to electric furnace conferences has just been released under the title **Index, Electric Furnace Steel Conferences, 1943-1957.** Those who attended the 1958 Conference will receive the Index together with their proceedings volume.

This easy-to-use reference provides three methods of finding a paper: title indexing according to a general subject area; indexing by author name; and a straight subject index. Many other valuable facts are included in the Index, such as an alphabetical list of speakers, toastmasters, members of electric furnace committees; and historical data on past Conferences.

To Fete Award Winners At Annual Meeting

Conferring of awards each year plays a major role at the AIME Annual Meeting. The following awards of interest to metallurgists will be presented in New York Feb. 14-18:

The James Douglas Gold Medal—to Augustus B. Kinzel "for outstanding contributions and inspiring leadership in the field of electrolytic and electrothermic winning of nonferrous metals, and for his notable adminstrative ability." Dr. Kinzel, vice president in charge of research, Union Carbide Corp., was the 1958 president of AIME. More recently, he has been named the 1960 president of the Engineers Joint Council (see story p. 58).

Extractive Metallurgy Division Award—to W. V. Barker, R. C. McQuire and L. S. Renzoni for their paper *Direct Electrorefining of Nickel Matte*, which appeared in the June 1958 issue of JOURNAL OF METALS. The award is made annually for the "best paper in the field of extractive metallurgy." The award is being conferred on Mr. McQuire posthumously.

The Benjamin F. Fairless Award—to Charles M. White, Chairman of the Board, Republic Steel Corp., "for his ability, energy, and determination in starting the top-pressure blast furnace and his foresight in providing it with prepared burdens which have created the world's dominant metal producer."

Robert W. Hunt Award for 1960—to T. E. Dancy, H. N. Lander, and A. T. Sadler for their paper on *Process Analysis of Blast Furnace Operation with Oxygen and Steam*, published in the 1958 **Blast Furnace Coke Oven and Raw Materials Proceedings.** It is awarded by the Iron and Steel Div. for the "best original paper or papers on iron and steel."

J. E. Johnson, Jr., Award for 1960—to Harry Holiday, Jr., superintendent of blast furnaces, Armco Steel Corp., "in recognition of his contribution to the production of very large tonnages in blast furnaces, achieved through the skillful use of agglomerated materials and operating practices." The Iron and Steel Div. each year bestows the award on a metallurgist, under 40 years of age, who makes a significant contribution to the manufacture of pig iron.

Mathewson Gold Medal—no award will be presented in 1960, according to an announcement by Prof. Robert Maddin, chairman of the School of Metallurgical Engineering, University of Pennsylvania, and chairman of the Mathewson Gold Medal Committee.

Rossiter W. Raymond Award for 1960—to Paul G. Shewmon, assistant prof. of metallurgy, Carnegie Institute of Technology, for *The Redistribution of a Second Phase During Annealing in a Temperature Gradient*, published in TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME, June 1958. Dr. Shewmon will also receive the Alfred Noble Prize for 1959 in recognition of this paper (See October 1959 JOURNAL OF METALS, p. 703).

Robert H. Richards Award for 1960—to Norman Weiss, milling engineer, American Smelting & Refining Co., "for his contributions to mineral engineering . . . in particular for his development and application of differential flotation and cyanidation to complex base and precious metal ores, his outstanding work in mill design, and his formulae for extraction and efficiency determinations . . ."

William Lawrence Saunders Gold Medal Award for 1960—to Robert J. Linney, executive vice president, Reserve Mining Co., "for administrative leadership and aggressive determination in bringing mining and beneficiation of taconite iron ore into successful commercial operation."

John Price Hirth Given Hardy Gold Medal for 1959

John Price Hirth has been named as the 1959 recipient of the AIME's Robert Lansing Hardy Gold Medal.

Dr. Hirth, a member of the Pittsburgh section, is now assistant professor of metallurgical engineering, Carnegie Institute of Technology. The Medal, first awarded in 1957, was established by Arthur C. Hardy, Massachusetts Institute of Technology, in memory of his son, who died in 1954 while a student at MIT.

The Medal is given to a nominee by AIME local sections, under 30 years of age, who is adjudged most promising in the field of metallurgy. Dr. Hirth, who received his Ph.D. from MIT in 1957, spent 1957-1958 as a Fulbright Research Fellow at Bristol University (England).

H. R. Spedden of the New York section headed the Hardy Award Committee which brought Dr. Hirth's name before The Metallurgical Society's Board of Directors on Nov. 3rd for final approval.

Last year's Hardy Medal winner was Robert A. Huggins of Stanford University. The first award was made to D. W. Fuerstenau of the Niagara Frontier section.

Egon Orowan Awarded Rheology Society Metal

Egon Orowan, professor of mechanical engineering, Massachusetts Institute of Technology, has been awarded the Bingham Medal by the Society of Rheology.

The award was made for Dr. Orowan's "creative imagination in discovering many secrets of the solid state of matter, and particularly his contribution to the understanding of the phenomena of plastic flow and fracture." Scene of the presentation was the 30th anniversary banquet of the Society of Rheology, meeting on the Lehigh University campus.

Dr. Orowon is Westinghouse Professor of Mechanical Engineering at MIT. From 1939-1950 he was in charge of the metal physics group in the Cavendish Laboratory at Cambridge University (England). In 1946 he received the Thomas Hawksley Award of the Institution of Mechanical Engineers (London), for his theory of metal rolling. In 1949 he delivered the Institute of Metals Division's annual lecture at the Annual Meeting. His subject was *The Structure of the Cold-worked Metal.*

Business Meeting

The regular Annual Business Meeting of the AIME will be held Tuesday afternoon, Feb. 16th, at the Statler-Hilton Hotel, following the All-Institute Session at the Annual Meeting in New York.

Society Members Among Nuclear Society Fellows

Three members of The Metallurgical Society are among recently elected Fellows of the American Nuclear Society. The group, the first to be so honored, was selected on the basis of "scientific and engineering attainment."

Those named are Frank G. Foote, Argonne National Laboratory; G. H. Gurinsky, Brookhaven National Laboratory; and John P. Howe, Atomics International.

SURFACE PHENOMENA—ANNUAL MEETING INTER-SOCIETY SYMPOSIUM TOPIC

Surface Phenomena for Mineral, Ceramic, and Metallurgical Systems is the theme of an Annual Meeting symposium being jointly sponsored by the Minerals Beneficiation Division, Society of Mining Engineers, and The Metallurgical Society.

The Symposium is an outgrowth of planning by the recently-formed Basic Science Committee of The Minerals Beneficiation Division. They have attempted to cut across society boundaries by choosing a topic of mutual interest to miners and metallurgists. Such a topic is surface phenomena.

Two sessions are planned for the Statler-Hilton Hotel on Feb. 17th. The following papers are slated for the morning session:

Elementary Concepts of Surface Energy and Their Applications in the Metallurgical Industry, by Cyril S. Smith, University of Chicago; *The Influence of Solutes on Interfacial Tensions and on the Contact Angle*, by J. Th. G. Overbeek, University of Southern California; *Kinetics of Wetting and Surface Energies of Solid Metals*, C. M. Adams, Massachusetts Institute of Technology; and *Some Aspects of the Foaming of Fused Silicates*, by C. F. Cooper and C. L. McCabe, Carnegie Institute of Technology.

In the afternoon, David Turnbull, General Electric Co., will discuss *Crystal Growth in Solids*. Also scheduled are *Surface Chemistry and Kinetics of Sintering Processes*, by W. D. Kingery, Massachusetts Institute of Technology; *Geometric Equilibria and Nonmetallic Microstructures*, by L. H. Van Vlack, University of Michigan; and *Graphite Formation and Surface Tension in Cast Iron*, by Jack Keverian, General Electric Co.

Chairman for the all-day meeting will be P. L. de Bruyn, Massachusetts Institute of Technology.

LD Pitted Against Open-Hearth Steelmaking at Buffalo Meeting

Hamilton, Ontario, Canada, was the scene of the latest skirmish between oxygen steelmaking and the traditional open-hearth process. Battle grounds was the 10th Annual Fall Meeting of the Buffalo section, National Open Hearth Steel Committee, held at the Royal Connaught Hotel on Tuesday, Nov. 10th.

Two hundred onlookers witnessed round one of the contest, a morning trip to the oxygen steelmaking plant of Dominion Foundries and Steel Ltd. Here the "fight fans" watched the fancy footwork of three LD vessels, two in use at any one time while the third is being relined. Under these conditions, a heat is tapped every 34 min. Oxygen flow rate averages 4000 to 6000 cu ft per min. Ingots are bottom poured.

After a recess for luncheon, courtesy of the Suppliers' Committee, the contestants squared off for round two at the technical session. Serving as referees were the two session chairmen, N. W. Fennie, open hearth superintendent, Lackawanna plant, Bethlehem Steel Co., and C. Reed, Dominion Foundries and Steel Ltd. (Dofasco).

Representing the challengers was Donald MacFarlane of Dofasco, who described their experience with the oxygen steelmaking process. Defending the title for open-hearth steelmaking was T. B. Winkler, division head, Research dept., Bethlehem Steel Co., who described their experience with oxygen roof lances at Lackawanna and Sparrows Point plants. Mr. Winkler compared the increase of production obtained with one, two, or three lances per furnace and influenced by such variables as oxygen flow rate, height of lance above bath, and nozzle size. He also described variations in furnace construction through use of basic roofs and silica end walls, and vice-versa.

Dealing another blow against the LD process was Donald Sloan, Steel Co. of Canada, Hamilton, Ontario, who related his Company's experience in using lances inserted in open-hearth furnace roofs at differing angles. James Morrill, combustion engineer, Republic Steel Corp., Buffalo, continued with a description of the combustion engineer's role in developing better refractories for open hearths. The final contestant in the technical meeting was Charles Moyer, open hearth supt., Republic Steel Corp., Buffalo. He described how successful basic roof performance at his plant increased the availability of furnaces through less down time and, therefore, increased production.

The final round of the verbal stand-off took place at the predinner cocktail party and in other informal gatherings by conference registrants.

Concluding the day's program was a banquet featuring "Jim" Trimble, Coach of the Hamilton Tiger Cats, who spoke on *A Comparison of Pro Football in the US and Canada*. Charles E. Moyer, Section chairman, presided at the banquet. Supervising arrangements for the conference once again was the genial Harry A. Morlock of General Refractories Co., Buffalo.

Kinzel Elected 1960 President of EJC

A. B. KINZEL

Augustus B. Kinzel will be the 1960 President of the Engineers Joint Council. The Council, composed of 21 professional societies, including the AIME, represents a membership of 300,000 engineers. Dr. Kinzel was the 1959 vice president of the organization. In 1958, he was president of the AIME.

Vice president in charge of research, Union Carbide Corp., Dr. Kinzel has been engaged in research there for over 30 years. He is known as a pioneer in the theory of stainless steels, having more than 40 patents issued in his name. He has also authored more than 60 technical papers on various phases of metallurgy. Long active in The Metallurgical Society of AIME, Dr. Kinzel is also known for his contributions to powder metallurgy. This year he was awarded the Stevens Institute of Technology's Powder Metallurgy Medal for is "outstanding achievement in the field of powder metals."

Call for 1960 Dues

AIME dues for 1960 are payable Jan. 1st as follows: Members and Associate Members, $20; Junior Members for the first six years of Junior membership, $12; thereafter, $17; Student Members (including an annual subscription to a monthly journal), $4.50.

Dues bills were mailed in early November. Prompt payment will assure uninterrupted receipt of publications in 1960. If, for any reason, a bill has not been received, the AIME headquarters should be notified.

AIME

BOARD OF DIRECTORS

Recent actions taken by the Institute Board of Directors.

► Honorary membership has been conferred on Andrew Fletcher "for his outstanding leadership in the lead and zinc mining industries, and for his able and devoted services to the Institute as its Treasurer and President, and as a Director for many years."

► E.C. Rudolphy, Chicago section, has been appointed to the committee making arrangements for the Eighth Joint Engineering Management Conference, to be held Sept. 15-16 in Chicago.

► Election to the Legion of Honor has been conferred on the following members who joined the Institute in 1910, maintaining 50 years continuous membership:

Charles, W. W., Jr.
Chedsey, William R.
Cooper, Maurice D.
Crease, Herbert H.
Daniell, John, Jr.
Fies, Milton H.
Fujita, Heitaro
Harder, E. C.
Harrison, Thomas S.
Laurie, Frank C.
Merrill, Pomeroy C.
Mitke, Charles S.
Stickney, Alfred W.
Taber, Stephen
Tyssowski, John
Wade, William R.
Wolflin, Hugh M.

► The following members have been elected to Senior Membership:

Archibald, R. S.
Cullity, Emmet R.
Estes, Frank M.
Graham, John F.
Grissom, Roy J.
Haultain, H. E. T.
Hochschild, Sali
Ingersoll, Guy E.
Montoulieu, Eduardo I.
Neustaedter, H. A.
Reagan, W. J.
Smith, Gordon Co.
Walter, A. B.

► The AIME Board of Directors has voted to support the election of Sylvanus Thayer to the Hall of Fame for Great Americans. Mr. Thayer, appointed superintendent of the U. S. Military Academy at West Point in 1817, is known as the father of engineering education in this Country, having inaugurated the first formal curriculum of engineering.

West Indies Beckons Annual Meeting Tourists

The West Indies is this year's port of call for the Annual Meeting post-convention trip. A choice of three tours of Caribbean islands is on the itinerary.

A seven-day vacation at Ciudad Trujillo, Dominican Republic, embarks from Idlewild International Airport on Friday afternoon, Feb. 19th. Headquarters in Ciudad Trujillo will be the Hotel Embajador International. Round-trip tourist flight plus double-room hotel occupancy adds up to a price of $298.50 per person ($338.20 for return to Miami). Included are six nights at the Hotel, six continental breakfasts, six dinners; sightseeing tours, and special events such as cocktail parties and golf tournament.

The second choice open to winter vacationers follows the first until the morning of Feb. 24th, when they fly to San Juan, Puerto Rico. After brief sightseeing, it's off to the city of Ponce, 30 air minutes to the South. Here guests will be lodged at the Hotel Ponce Intercontinental. This is an eight-day junket, with departure the afternoon of Feb. 26th. Price for this trip variation, as in others, includes hotel, meals, transportation, sightseeing, and recreation. Per person price (based on double-room occupancy) is $396.50. Single-room rates in all three trips call for an additional fee. Return to Miami is available at the same price.

Ciudad Trujillo, Dominican Republic, San Juan, Puerto Rico, and St. Thomas, Virgin Islands, pose the third trip alternative. This is also an eight-day junket, beginning in Ciudad Trujillo, moving to San Juan with the Ponce group, and continuing on that same afternoon of the 24th to Bluebeard's Castle Hotel at St. Thomas. Departure for New York or Miami is with the Ponce group on Feb. 26th. Per person charge (double-room occupancy) is $436.50. The usual compliment of features is included.

For additional details, contact: Theilig International Tours, Daily News Plaza, Suite 2111, 400 West Madison St., Chicago 6, Ill.

Woman's Auxiliary Offers Annual Meeting Wives Full Schedule

A full schedule of luncheons, fashion shows, and scenic tours is on tap for the wives of Annual Meeting registrants. Tickets and information will be available at the Hotel Statler headquarters in New York, beginning at 1:00 pm, Sunday, Feb. 14th. Wives are urged to register before trying to purchase luncheon tickets, since registration badges must be shown in order to purchase tickets.

Members of the Woman's Auxiliary, AIME, will be on hand to assist New York visitors. Officers of the Auxiliary for 1959-1960 are Mrs. Andrew E. Beer, president; Mrs. Lyman H. Hart, first vice president; Mrs. John Mann, second vice president; Mrs. Edward P. Chapman, Jr., third vice president; Mrs. R. A. Cattell, fourth vice president; Mrs. Thomas Allen, fifth vice president; Mrs. Arnold H. Miller, recording secretary; Mrs. Rene J. Mechin, asst. recording secretary; Mrs. Harris W. Grose, corresponding secretary; Mrs. John A. Poulin, asst. corresponding secretary; Mrs. Robert W. Rowen, treasurer; Mrs. Samuel Dolbear, asst, treasurer; and Mrs. Roger Sherman, asst. treasurer.

Hazards of Metal Powders Cited at New York Meeting

The Powder Metallurgy Group of the New York section, AIME, met at the Brass Rail Restaurant on Nov. 18th to hear a talk on *Pyrophoricity and Toxicity of Metal Powders* by Herbert S. Kalish, chief of the Materials Section, Nuclear Fuel Research Laboratories, Olin Mathieson Chemical Corp. He explained that fire and explosion hazards from use of metal powders increases as powders become more finely divided. Below a critical diameter of 50 μ powders will remain suspended in air. Ignition temperature is lowered as average diameter decreases. Most dangerous is uranium powder, followed by zirconium, titanium, thorium, iron oxide, aluminum, and manganese, in that order. Mr. Kalish recommended the following safety precautions:

1) Keep the room clean so powders do not accumulate; and
2) Minimize turbulence.

Toxicity results from inhalation of metal powders, he explained. Since the threshold of toxicity is difficult to determine, safety limits are set high. Most toxic is plutonium; next is beryllium, then nickel, mercury, chromium, and cadmium as oxides, followed by tellurium, zirconium, zinc, titanium, and iron oxides in that order.

STUDENT NEWS

What better way to usher in a new year than with the addition of a new feature to the magazine. There is an ever-growing audience of student members of The Metallurgical Society (833 as of Dec. 1st) who have gone neglected up 'til now. We hope to make this a continuing feature, and with the cooperation of student members, officers, and faculty sponsors alike, we will be able to do so. These columns should prove a source of ideas which will help make your chapter better. So keep the JOURNAL OF METALS office posted on your activities that the membership-at-large may know what you are doing.

Cornell University

Each Fall the Cornell student metallurgical society makes its first meeting a get-acquainted one for students and faculty of the Metallurgical Engineering Department. This year it was a Freshman Initiation Picnic at Upper Enfield State Park. The relaxed atmosphere brought faculty members and their classroom charges together on a professional interest level, besides giving chapter members a chance to unlimber their football prowess in preparation for an upcoming game with the chemical engineering majors.

The Cornell Metallurgical Society, as the chapter is called, was founded in 1949, with Prof. James L. Gregg as its original advisor. The purpose of the Society is to stimulate and hold the interest of undergraduates in the field of metallurgy in order that they may attain better grades, while instilling a feeling of professional pride which at the same time will insure a higher percentage of persons who stay in and graduate in metallurgy. It also aims to promote better inter-class relationships among student metallurgists, as well as effecting closer student-faculty ties.

Prof. Clyde W. Mason served as faculty advisor from 1953-1955, and Prof. Chester W. Spencer is currently in that capacity.

On hand for the picnic were Jim Forden, George Winters, Tom Munsch, Bob Filner, Andy Rigrod, Gary Weale, Aaron Blechman, Simon Segal, Jim Tabor, Andy Sheren, Ed Aigeltinger, Ilona Forgeng, Rob Dill, Jack Finnegan (1959-1960 president of the Society), Jerry Miller, (vice president), Charles Torrey (secretary), Mr. and Mrs. George Bishop, Mr. and Mrs. Bob Hendricks, Mr. Lin, Professor and Mrs. G. V. Smith, Professor and Mrs. C. W. Spencer, Professor and Mrs. M. S. Burton, and Professor J. L. Gregg. Tom Smith is treasurer of the Society.

Carnegie Institute of Technology

The Student Metallurgical Society of Carnegie Tech listened to *What Computers Can Do* at its Oct. 26th meeting. Speaker of the evening was Dr. Perlis, of the Institute. Following the talk and announcements, the group of 40 moved to the next room where refreshments were served.

Current Society officers, whose term of office expires Feb. 1st are:

Cliff Rowden, president; Mike Georgelis, vice president; Jim Beisler, treasurer; Hershell Tkatch, secretary; and Don Arnon, social chairman.

Purdue University

A talk on high-temperature alloys featured the Oct. 27th meeting of the Purdue Student Chapter, AIME. Speaker of the evening was B. R. Barrett, manager of product development, Haynes Stellite Co., div. of Union Carbide Corp. Donuts and punch provided the evening's refreshments.

Officers of the Chapter, term expiring in May are:

Llyod A. Swanson, president; Jon Nelson, treasurer; and Ed Hargitt, secretary. C. E. Anderson is Publicity chairman; with Phil Hudson, Refreshments; and Jon Nelson, Program chairman.

Case Institute of Technology

The retiring officers of the Case chapter of The Metallurgical Society are:

Charles Rosner, president; William Breittig, vice president; James Rudge, secretary; and Lawrence Draper, treasurer. Social chairman was Michael Whiteman; and Program chairman, Michael Rabitt. Election of 1960 officers will be held this month.

Ohio State University

Current officers of the combined AIME-AFS chapter on the campus, terms expiring in June, are:

Rus Orkin, president; William Sivakoff, vice president; and Thomas Fanow, secretary-treasurer.

Illinois Institute of Technology

Metals Club officers on the Illinois Tech campus, term expiring in June are:

D. C. Brillhart, president; John Henry, vice president; R. W. Lobenhofer, secretary; and Fred Gezella, treasurer.

Lafayette College

Lafayette College's metallurgical group met on Oct. 13th to hear a talk on hardening of austenitic manganese steel. Speaker of the evening was W. A. Harper, chief engineer, Taylor Wharton Co., Easton, Pa. Following the talk, came a tour of the Markle Hall labs, home

CORNELL PICNIC

of the Metallurgy Dept. on campus. Logically, the name of the student group is John Markle Society.

Ralph E. Jemison, Society president, conducted the meeting attended by 20 persons. In the business portion of the meeting, Charles Turk was elected secretary of the Society. Serving of refreshments followed the laboratory tour.

Massachusetts Inst. of Tech.

The October Meeting of MIT's Student Metallurgical Society was attended by a whopping 110. No doubt the huge turnout was due to the fact that it was the occasion for the chapter's traditional steak and beer party. The number represented over 50 pct of the school's metallurgy enrollment. Attendence by almost the entire metallurgy dept. faculty contributed to the success of the party.

Officers of the Society for 1959-1960, term expiring in May are:

Harold Brody, president; Susan Schur, vice president; William Wagner, secretary; and Herbert Berman, treasurer. Cyril M. Pierce and John R. Palmieri are co-chairmen of the Social Committee; with Nelson Hicks and Manuel Moreno chairmen of the program committee; Harvey Nesor, Publicity Committee; and Stephen Goodman, Membership.

New York University

New York University's student chapter officers for 1959-1960, term expiring in June are:

John Bilello, president; David Seidman, vice president; Sanford Adler, secretary; and Alan Goldman, treasurer. Chairman of the Film Committee is Alan Reinstein; while John Papazian is chairman of the Plant Trip Committee.

NEW STUDENT MEMBERS

University of Arizona

Walker, Clarence H., Jr.

University of British Columbia

Hawbolt, Edward B.
Mui, Joseph

University of California

Quimby, Richard M.

Carnegie Institute of Technology

Brosius, Robert N.
Broudy, Irving L.
Creazzi, Denis L.
Dominik, Lawrence A.
Friedman, Gilbert
Georgelis, Michael A.
Heiry, Denis D.
Hendrickson, Merlin
Johnson, Richard
Levine, Phillip J.
McIlwain, Donald
Miljus, Nathaniel
Patel, Sumantrai
Rowden, Clifford E.
Rzepka, Joseph F.
Saul, Robert H.
Smith, Richard D.
Stiehl, Robert L.
Tkatch, Hershell R.
Weller, Robert D.

Case Institute of Technology

Free, Thomas A.
Jekkals, Igo
Rabbitt, Michael L.

Colorado School of Mines

Biddle, Arthur
Blasing, Barry
Cline, William
Forest, Robert D.
Pace, James G.
PoSaw, Thein
Rairden, Paul A.
Reed, Richard P.
Reuter, Walter
Severns, Richard
Webster, Larry D.
White, Harry K.

Columbia University

Hamburg, Emil
Lee, Eun Li
Leppe, Arnaldo
Manocha, Rajindra
Mendoza, Virgilio
Symes, Ernest

Cornell University

Becker, Paul C.
Smith, James T.

Drexel Institute of Technology

Schuele, Werner, Jr.

University of Idaho

Hsi, Huey-rong

University of Illinois

Drews, Thomas
Follensbee, Thomas L.
Garza, Miguel
Larsen, Richard J.
Lotter, Richard J.
Mah, George
Stoltz, Daniel L.
Weiss, Carl D.

Illinois Institute of Technology

Coker, Glenn
D'Alessandro, Franklin
Kizior, Stanley
Lobenhofer, Roy

University of Kentucky

Glover, William
Grief, Arthur

Lafayette College

Kim, Hugh
Noble, George P., III

Lehigh University

De Paul, Robert
Reilly, Fairfax

Massachusetts Institute of Technology

Battat, Emil
English, Alan T.
Goldstein, Joseph
McMahon, Charles
Miller, Gary A.
Sipos, Donald J.
Taylor, John R.

University of Michigan

Smythe, John

Michigan College of Mines & Tech.

Pechauer, Thomas C.
Predmore, Roamer

University of Minnesota

Weltzin, Richard D.

Missouri School of Mines

Baluha, Gerald
Brament, Bruce
Dean, Richard O.
Eppelsheimer, Daniel
Hallerberg, William
Lewis, Joseph C.
McLane, William B.
Merryfield, Robert
Mills, Terry L.
Ogle, James
Toma, Robert F., Jr.

Montana School of Mines

Johnson, Robert E.
Martens, Robert
Speidel, Edward O.
Vivian, George L.
Wistehuff, William E.

New York University

Adler, Sanford C.
Besel, Fred A.
Bilello, John
Franko, John

City College of New York

Drobitsky, Karl

North Carolina State College

May, Vester

University of North Dakota

Bohn, James D.

Northwestern University

Agarwal, Gopal P.
DeAngelis, Robert
Greener, Evan
Kawai, Toshihiko
Kenny, Neal S.
Mikkola, Donald E.
Wimmer, Frank T.

University of Notre Dame

Feller, John R.
Fitzgerald, Thomas J.
Scherpereel, Donald E.

University of Oklahoma

Poirier, Raymond

Ohio State University

Flowers, James W., Jr.
Forrest, Andrew G., Jr.
Marohnic, Edward L.
Rausch, Doyle W.
Skora, Denis E.

University of Pennsylvania

Ginsberg, Michael

Purdue University

Anderson, Charles
Ayres, Paul
Gacic, Aleksander
Heckler, Alan
Hudson, Philip L.
Kassner, Thomas
Lodenkamper, John W.
Papazoglou, Thomas P.
Rivas, Luis
Sailors, Richard
Smith, Larry J.

Rensselaer Polytechnic Institute

Butrymowica, Daniel B.
Duhl, David
Salkind, Michael

South Dakota School of Mines & Tech.

Avotins, Peter
Bowman, Conrad
Murray, David

Stanford University

Hammond, Martin
McNulty, Terence

Texas A & M College

Pearson, Carl

Texas Western College

Pratt, Emron

University of Utah

Chase, Phillip D.
Jump, George
Moss, Timothy E.

Virginia Polytechnic Institute

Connell, Richard G., Jr.
Legacy, Donald J.

Wayne University

Calfin, Brent
Ledbetter, Hassell, Jr.

University of Wisconsin

Andrasco, Melvin
Beltran, Adrian
Dubberstein, Gordon
Guhl, Roland
Lawlor, Michael
Mosser, Raymond A.
Schley, Leo D.
Schroeder, William L.
Wissing, Thomas J.

Yale University

Gold, Michael

PERSONALS

(Continued from page 12)

Ohio, plant of Union Carbide Metals Co., div. of Union Carbide Corp. He was formerly asst. supt. in charge of titanium at Ashtabula.

Dillon Evers has joined the Management Committee of Sharon Steel Corp. in the capacity of consulting metallurgical engineer. Dr. Evers was previously associate director of metallurgy with Mallory-Sharon Metals Corp. Sharon Steel is a subsidiary of Mallory-Sharon.

John A. Succop has retired after 39 years with the Heppenstall Co., Pittsburgh. At his retirement, he was vice president in charge of metallurgy. He will continue to serve the company in the capacity of consultant.

Anthony L. Ascik is now director of Metallurgical Technical Services for Tennessee Products, subsidiary of Merritt-Chapman and Scott Corp. Prior to joining the company he was technical director of the Calvert City, Ky., plant of Pittsburgh Metallurgical Co.

Slight Ups and Downs Seen for B.S. Met; Mining Degrees Down

An increase in metallurgy degrees, to be followed by a slight dip in number, is predicted by the Engineering Manpower Commission of the Engineers Joint Council.

Although official 1959 figures have yet to be published by the US Office of Education, the Manpower Commission estimates 680 B.S. degrees in metallurgy were awarded in 1959. This compares to the 662 awarded in 1958. In 1960, it is estimated that 670 metallurgy degrees will be awarded.

As for mining engineering, a steady decrease in numbers is reported. The number of B.S. degrees in mining engineering was 220 in 1958. In 1959 it is expected to drop to 205, with 190 predicted for 1960.

Meanwhile, totals of bachelor degrees in engineering are also characterized by ups and downs. In 1958, 36,332 were issued, with 37,965 predicted for 1959. Projecting into 1960, however, it is expected that 37,415 will be awarded. These figures are based on a drop out rate which will see about 38,000 1959 survivors of some 72,825 freshmen in 1955. Although the entering freshman class in 1956 was larger—77,738—it appears that the drop out rate by 1960 will be even greater.

PROFESSIONAL SERVICES

Limited to AIME members, or to companies that have at least one AIME member on their staffs. Rates $50 per year per inch.

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Personals Form

▼**Personals:** Please list below your former company and title and your new title and company (or new work) for use in JOURNAL OF METALS. (Copy deadline for personals items is six weeks before date of issue.)

Former Company _____

Former Title _____ Length of Time There _____

New Company _____

New Company Address _____ Date of Change _____

New Title _____

Any recent activity that would be of interest to members:

_____

_____

_____

PROPOSAL FOR AIME MEMBERSHIP

I consider the following person to be qualified for membership and request that a membership kit be mailed to him:

Name of Prospective Member:

_____

Address

_____

_____

_____

Name of AIME Member:

_____

Address

_____

_____

_____

JM

AROUND THE SECTIONS

Philadelphia section heard a description of the National Academy of Sciences' *Operation Mohole* by the chairman of the committee on the project, Gordon G. Lill, at its Oct. 22nd meeting. Described were the procedures in exploration and drilling that will ultimately probe 9-mi into the earth.

The meeting was also featured by the awarding of prizes for the best student papers submitted to the Section's competition. A certificate, engraved silver ash tray, and $25 was awarded Marshall K. Thomas, Jr., of Drexel Institute of Technology, for the best undergraduate paper. Its subject was *Precipitation in Thermenol, an Iron-Aluminum-Molybdenum Alloy.*

Second prize went to John E. Moore, Drexel Institute, for *Mechanism of Sintering.* His prize was a certificate, engraved silver ash tray, and $10.

Next meeting for the Section will be Jan. 29th. This Annual Meeting will feature election of 1960 officers. Guest speaker will be Joseph L. Gillson, President-Elect of the AIME. The meeting has also been designated as "Ladies Night." For information, call: James M. B. Keyser, Secretary- Treasurer of the Section, at NIagara 4-8400 in Paoli, Pa.

Cleveland, section, NOHC, will hear a description of the effects of the prolonged steel plant shutdown at its Jan. 14th meeting. Scene of the meeting will be the Rockside Gardens in Cleveland.

Hudson-Mohawk section heard a discussion of *Controlled Freezing as a Metallurgical Technique* at its Nov. 20th meeting. William G. Pfann, Bell Telephone Laboratories, delivered the talk. Meeting place for the 40 in attendance was the General Electric Research Laboratory in Schenectady. During the business portion of the meeting Section Chairman A. A. Burr urged members to support the United Engineering Center Building Fund. He called for each engineer in the area to recognize his responsibilities in supporting this "much-needed and ambitious undertaking."

The subject of the forthcoming columbium symposium also came up. June 9-10, 1960, are the dates of the Symposium, to be sponsored by the Hudson-Mohawk group. Watch for further details on the meeting as they become available.

The section's next meeting will take place this month at Rensselaer Polytechnic Institute. Dr. R. F. Davis will speak on *Explosive Loading of Metals.* For further details, contact: Jack Keverian, Section Secretary, at the Foundry Dept., General Electric Co., Bldg. 93, Rm. 102, Schenectady.

Southern California section's Metals branch will hold its next meeting Jan. 14th at the Rodger Young Auditorium. Speaker of the evening will be David B. Wittry, assistant prof. of electrical engineering, University of Southern California. Dr. Wittry will discuss *Studies of Metallurgical and Solid State Problems with the Electron Probe Microanalyzer.* In his talk he will give the principles behind electron probe analysis, followed by recent applications, e. g., concentration profiles in chromized iron. . .phase identification in Ti-Cu and Ti-Ag alloys and also alloys involved in attaching leads to transistors . . . diffusion of nickel ions in single crystal sapphire . . . diffusion of zinc in gallium arsenide . . . diffusion of arsenic into germanium and germanium with aluminum regrowth . . . solubility of gallium in germanium . . . and analysis of the Widmanstaten structure in meteoritic iron.

For reservations by card or phone, contact: Jim McCaldin, MAdison 9-3261, Ext. 236, Hughes Products, P. O. Box 278, Newport Beach.

Pittsburgh section's IMD group will meet at the Pittsburgh Hilton Jan. 21st. Leading off the meeting will be a 5:30 pm cocktail hour. The 6:30 dinner will be followed by the business portion of the meeting. Speaker of the evening will be Dr. C. A. Wert of the University of Illinois, who will talk on the *Interaction of Carbon and Nitrogen with Dislocations in Iron.*

Ohio Valley section heard Fred Bagby, Battelle Memorial Institute, speak on *Metals in Space* at its Nov. 12th meeting in Columbus.

San Francisco section was entertained by the student sections of Stanford University and the University of California on the Stanford campus Nov. 18th. Stanford students also conducted the program, which featured a *Magnetic Survey of the Bay Area,* by William Clement; *Observations of Permafrost,* by John Cole; *The Electron Probe,* by Ray Dils; and *Measuring Surface Subsidence Near Pumping Wells,* by Frances Riley. A total of 123 persons attended, including 53 students. Presiding officers for the meeting were San Francisco section chairman L. T. Kett and Evan Just of Stanford.

Connecticut section will offer the second in a series of meetings on materials engineering on Jan. 13th, when Julius J. Harwood, head of the metallurgy branch, Office of Naval Research, will speak on *the Materials Research Program Sponsored by the U S Government.* The New Haven meeting will also be featured as Students Night.

The first of the series on material research was held Nov. 12th. James H. Bechtold, Westinghouse Electric Corp., addressed the gathering on *Design and Development of Materials.* The meeting, also billed as President's Night, featured President-Elect Joseph L. Gillson, who spoke on *Aims of AIME.*

(Continued at top of next page)

DIGNITARIES—Among those at the Nov. 12th meeting of the Connecticut section were: l to r, R. S. Bray, Vice Chairman, Connecticut section, J. L. Gillson, AIME President-Elect, Ernest Kirkendall, AIME Secretary, and R. M. Treco, Connecticut section Chairman.

New York section's November meeting evoked a discussion of *The Fuel Cell*, as precipitated by George E. Evans, director of research, Union Carbide Consumer Product Co., div. of Union Carbide Corp. Not only did Dr. Evans discuss, but opening a suit case, he produced a real live fuel cell operating a fan and a blinking light. This served to emphasize the recent scientific and technological advances that point to the practical use of the fuel cell as a power source. But fuel cells, which convert chemical energy into electric power at exceedingly high efficiencies, are anything but new in concept, the first fuel cell being developed in 1839. At the turn of the century, the fuel cell was at a stage of development comparable to that of the less-efficient internal combustion engine, but since then the main line of emphasis has been on the latter. Now there is a revival of interest in the fuel cell.

Dr. Evans described seven different types of cells, including those operating at high pressures and temperatures up to 800°C. Others operate at temperatures of about 200°C and pressures up to 600 psi. These cells generally make use of acqueous fuels, either directly or indirectly, as in the case of the Redox cell. One line of development being pursued by Union Carbide is that of the low-temperature, low-pressure cell using pure nickel electrodes and potassium hydroxide electrolyte. At present there are no commercial applications of the fuel cell, but a number of firms are working actively to bring the fuel cell down to the economic level which would permit its utilization.

Boston section considered problems of membership continuity and local policy matters at its Nov. 30th meeting at the MIT Faculty Club in Cambridge. The dinner-business meeting was host to AIME President Howard C. Pyle, making his appearance at the Section's annual President's Night.

Detroit section's Nov. 16th meeting featured a talk on the *Relationship of Nuclear Resonance Studies to Interatomic Bonding and Alloy Theory*, by Richard A. Oriani, assistant director, U. S. Steel Corp's Fundamental Research Laboratory. Keith McKee, Section technical chairman, presided.

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on Dec. 1, 1959, was 33,172 in addition 3,317 Student members were enrolled.

ADMISSIONS COMMITTEE

L. L. Seigle, Chairman; W. L. Bryteruk; F. B. Foley; T. D. Jones; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Aisop, Farrel, Salt Lake City, Utah
Bammert, Albert, Quebec, Ontario, Canada
Barrow, Robert, Rochester, N. Y.
Beard, Arthur, Schenectady, N. Y.
Berber, John, Reno, Nev.
Burns, James, Los Angeles, Calif.
Chessin, Henry, Monroeville, Pa.
Chiotti, Primo, Ames, Iowa
Clarke, Milton, Portland, Ore.
Gazzara, Charles, Watertown, Mass.
Gloven, Daniel, Everson, Pa.
Golestaneh, Ahmed, Erie, Pa.
Gondolf, Ewald, Voelklingen, Germany
Gosch, Don, Plainfield, N. J.
Guettel, Charles, East Orange, N. J.
Henry, William, Jr., Fairfield, Ala.
Huntington, John, New Hartford, N. Y.
Ide, Ruth D., Morristown, N. J.
Jacobson, Henry, Silvermine, Conn.
Kane, Alexander, Helena, Mont.
Knox, John, Mountainside, N. J.
Komatsu, Noboru, Cambridge, Mass.
Kunz, Fred, Troy, N. Y.
Lachman, John, Cincinnati, Ohio
Li, James C. M., Monroeville, Pa.
Lusby, William E., Jr., Wilmington, Del.
Mangelsdorf, Paul, Jr., Chicago, Ill.
Martin, George, Los Angeles, Calif.
Marx, Victor, Philadelphia, Pa.
May, John, Pittsfield, Mass.
McClure, Alex, Alameda, Calif.
McNeish, William A., Bridgeville, Pa.
Muecke, Henry, Chicago, Ill.
Noesen, Stanley, Schenectady, N . Y.
Paprocki, Stan, Columbus, Ohio
Perkett, Robert, Hoyt Lakes, Minn.
Rech, Kenneth, Blue Island, Ill.
Rees, William H., Detroit, Mich.
Roath, Edward, Rumford, R. I.
Roberts, Lee, Jr., Hayward, Calif.
Schneider, Philip, Coatesville, Pa.
Skinner, G. M., Indianapolis, Ind.
Stalhed, John, Stockholm, Sweden
Thomas Joseph, Pittsburgh, Pa.
Thomson, Robb, Urbana, Ill.
Vandroffelaar, Hendrik, Prescott, Ont., Canada
Wagner, Christian, New Haven, Conn.

Associate Members

Brooks, Merton, Niagara Falls, N. Y.
Burdenski, Thomas, Norridge, Ill.
Greeson, Richard, Boulder, Colo.
Gould, Harold, Canoga Park, Calif.
Hopkins, Harlan, Cincinnati, Ohio
McGavitt, Paul, Parma Heights, Ohio
Tiller, William, Pittsburgh, Pa.

Junior Members

Bolling, Gustaf, Pittsburgh, Pa.
Coldren, Arthur, Ann Arbor, Mich.
Contreras, Miguel, Caracas, Venezuela
Cutler, James, Suffield, Conn.
Duhan, John, La Oroya, Peru
Freda, August, Pittsburgh, Pa.
Hamel, William G., Mayfield Heights, Ohio
Heitzmann, William E., Dolton, Ill.
Hudson, John B., Schenectady, N. Y.
Hunter, James, Schenectady, N. Y.
Iannielio, Louis, Mechanicville, N. Y.
Lam, Daniel, Troy, N. Y.
Liebmann, Wolfgang, Philadelphia, Pa.
Linney, Joseph, Mayfield Heights, Ohio
Lynch, Peter F., Attleboro, Mass.
Mori, Tsutomu, Evanston, Ill.
Mosby, James, St. Louis, Mo.
Mower, Frederick J., Towanda, Pa.
Oldrieve, Robert, Sandusky, Ohio
Reichel, Carl, Chicago, Ill.
Rothstein, Paul, Bronx, N. Y.
Severson, Marshall, Hammond, Ind.
Strudwick, Thomas, Manasquan, N. J.
Sundram, C. V., Bombay, India
Weigle, John B., Bethlehem, Pa.
Yeniscavich, William, Pittsburgh, Pa.

REINSTATEMENT
Member

Hammond, Joseph, Knoxville, Tenn.
Senior, Frank, Niagara Falls, Ont., Canada
Trout, H. E., Jr., Glenshaw, Pa.
Whittington, Russell, El Paso, Tex.

REINSTATEMENT—CHANGE OF STATUS
Junior to Member

Bernstein, Leonard, Fullerton, Calif.
Mueller, William M., Denver, Colo.

Student to Member

Buchanan, John M., Trail, B. C., Canada
Morgan, Richard, Ecorse, Mich.

Student to Junior

Moberg, Duane V., E. Moline, Ill.
Walton, Derek, La Jolla, Calif.

CHANGE OF STATUS
Junior to Member

Bennett, Beresford, Welling, England
Coolbaugh, William, Pery, Ill.
Darby, Joseph, Lemont, Ill.
Elliott, Rodney, Chicago, Ill.
Feir, Marvin, Willimantic, Conn.
Fountain, Richard, Niagara Falls, N. Y.
Hill, Maynard, Pittsburgh, Pa.
Komarek, Kurt, New York, N. Y.
Landig, Thomas, Glenshaw, Pa.
Litman, Arnold, Oak Ridge, Tenn.
Lloyd, Richard, New York, N. Y.
McHarque, Carl, Oak Ridge, Tenn.
McManus, James, Texas City, Tex.
Opinsky, Arthur, Bayside, N. Y.
Perkins, Roger, Fair Oaks, Calif.
Peters, Ernest, Vancouver, B. C., Canada
Purdy, Samuel, Reading, Pa.
Semmel, John, Wyoming, Ohio
Smith, Phillip, Chicago, Ill.
Smithmeyer, Frederick, Lawrence, Kans.
Starratt, F. Weston, Brooklyn, N. Y.
Wagner, Richard, Murray Hill, N. J.
Weertman, Johannes, New York, N. Y.
Weil, Rolf, Hoboken, N. J.

Student to Member

Peckner, Donald, New York, N. Y.

SPECIAL REINSTATEMENT
Junior Member

Olsen, Melvin G., Redstone Arsenal, Ala.

NECROLOGY

Date Elected	Name	Date of Death
1958	Burgess, Keith N.	Mar. 6, 1959
1928	Crosby, Irving B.	Sept. 18, 1959
1916	Deussen, Alexander	Sept. 5, 1959
1947	Elayer, Carl S.	Oct. 17, 1959
1917	Hahn, Albert W.	October 1959
1937	Hamblen, K. E.	Unknown
1915	Harrison, Perry G.	Nov. 11, 1959
1919	Hulin, Carlton D.	Oct. 8, 1959
1939	Lord, T. V.	Oct. 13, 1959
1911	Manahan, R. F. (Senior Member)	June 30, 1959
1918	Penick, Walter L.	Nov. 11, 1959
1897	Weck, Charles A. (Legion of Honor)	Nov. 2, 1959
1951	Whitford, Hedley N.	Oct. 13, 1959

OBITUARIES

Burgess, Keith N. (junior member 1958) died at his home in Billings, Mont., Mar. 6th. Before moving to Montana, Mr. Burgess was a metallurgical engineer with Pratt & Whitney Aircraft, div. of United Aircraft, Middletown, Conn. He majored in physical metallurgy at the Montana School of Mines, graduating in 1953.

Lord, Theodore V. (member 1939) died at Kingston, Ontario, Canada, on Oct. 13th at the age of 66. Professor Lord was head of the department of metallurgy at Queen's University in that city from 1938 until his retirement last year. He was especially known for his studies in flotation, contributing to the literature on the subject. Besides membership in the AIME, Professor Lord was a member of the Canadian Institute of Mining and Metallurgy.

ANNUAL MEETING — TECHNICAL PROGRAM

The Metallurgical Society of AIME

Februrary 14 to 19,1960

Sheraton-Atlantic and Statler Hilton Hotels, New York

Condensed Program - Technical Sessions, Sheraton-Atlantic Hotel, New York

	Ballroom	Winter Garden	Colonial Room	Green Room	Red Room	Blue Room
Sunday, Feb. 14, 2:30 pm					Symposium on Metallurgic Education	
Monday, Feb. 15, 9:30 am	Forum on Metallurgy in the Navy (IMD)	Direct Reduction of Iron Ore (ISD)	Physical Chemistry of Extractive Metallurgy (EMD)	Hydrometallurgy (EMD)		
Monday, Feb. 15, 2:30 pm	Forum on Metallurgy in the Navy (IMD)	Fundamental Studies (ISD)	Int. Symposium on Extractive Met. of Copper, Nickel and Cobalt —General (EMD)	Electrolytic Processes (EMD)		
Tuesday, Feb. 16, 9:00 am 11:00 am	Iron and Steelmaking (ISD) Howe Memorial Lecture (ISD)		Int. Symposium--Fuel Fired Smelting and Converting (EMD)	Refractories (EMD)	Diffusion (IMD)	Orientation and Textures (IMD)
Wednesday, Feb. 17, 9:00 am*	Solidification I (ISD-IMD)		Int. Symposium—Electric Furnace Smelting (EMD-ISD)	Uranium, Rare Earths, and Minor Metals (EMD)	Dislocations I (IMD)	Phase Transformations and Segregation (IMD)
Wednesday, Feb. 17, 2:00 pm*	Solidification II (ISD-IMD)		Int. Symposium—Atmospheric and Elevated Pressure Leaching (EMD)	Nuclear Fuels Reprocessing (EMD)	Dislocations II (IMD)	Experimental Techniques and General Metallurgy (IMD)
Thursday, Feb. 18, 9:00 am 11:00 am	Light Metals (EMD) EMD Lecture	Acid Converter and Basic Oxygen Steelmaking I (ISD)	Aqueous Electrolytic Process and Related Operations (EMD)	Titanium (IMD)	Deformation and Fracture I (IMD)	
Thursday, Feb. 18, 2:00 pm	New Developments in Extractive Metallurgy of Refractory Metals (EMD)	Acid Converter and Basic Oxygen Steelmaking II (ISD)	Int. Symposium—Refining (EMD)	Powder Metallurgy-Dispersion Hardening and Strengthening (IMD)	Deformation and Fracture II (IMD)	

* In addition, a Basic Science Symposium on Surface Phenomena for Mineral, Ceramic, and Metallurgical Systems will be held at the Sky Top Room, Statler Hilton Hotel (MBD-IMD-EMD).

SUNDAY, FEBRUARY 14, PM

Met Soc Panel Discussion
The Terminal B. S. Program in Metallurgical Engineering, Its Importance, Problems, and Future

(Arranged by Education Committee of The Metallurgical Society)

2:30 pm Sheraton-Atlantic Hotel Red Room

Morris Cohen, Moderator

Panelists:

W. R. Hibbard, Jr.—Industrial Viewpoint

R. Schuhmann, Jr.—Accreditation Criteria of the Engineers Council for Professional Development.

J. E. Dorn—Comparison With Metallurgical Programs Preparatory for Graduate Study.

Council of Education Social Hour

5:00 pm Statler Hilton Hotel Georgian Room

Council of Education Buffet Dinner

6:00 pm Statler Hilton Hotel Georgian Room

Council of Education Technical Session

8:00 pm Statler Hilton Hotel Gold Ballroom

MONDAY, FEBRUARY 15, AM

IMD
Metallurgy in the Navy—Requirements, Application and Research

9:00 am Sheraton-Atlantic Hotel Ballroom

Keynote Address: *Dr. Howard A. Wilcox*, Office of the Secretary of Defense, Deputy Director for Defense Research and Engineering.

Introductory Remarks: *James M. Wakelin*, Assistant Secretary of the Navy (Research and Development).

Technical Session: Materials Problems in Naval Weapons

Chairman: *N. E. Promisel*, Director of the Materials Division, Bureau of Naval Weapons.

Deep Submergent Vessels: *Captain T. B. Owens*, USN, Bureau of Ships.

Missiles and Other Aerial Vehicles: *W. S. Pellini*, Naval Research Laboratory.

Energy Conversion: *P. H. Egli*, Office of Naval Research.

TUESDAY, FEBRUARY 16

Met Soc Social Hour

6:00 pm Sheraton-Atlantic Hotel Winter Garden
(Cocktails Available)

Met Soc Annual Dinner

7:00 pm Sheraton-Atlantic Hotel Ballroom

John Chipman, President, Presiding

Speaker: Professor C. Stark Draper, Head, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology.

Subject: Guidance for Spacecraft

ISD Direct Reduction of Iron Ore

9:30 am Sheraton-Atlantic Hotel Winter Garden

Chairmen:

Rolf Nordheim, Jones & Laughlin Steel Corp.
K. M. Shupe, Latrobe Steel Co.

Reduction Kinetics of Magnetite in H_2-H_2O-N_2 Mixtures: *W. K. McKewan*, United States Steel Corp.

Nu-Iron, a Fluidized Bed Reduction Process for Iron Ore: *T. F. Reed, J. C. Agarwal*, and *E. H. Shipley*, United States Steel Corp.

Versatility of the R-N Process: *G. G. Reed, Jr.* and *R. P. Smith*, National Lead Co.

Phosphorus in the Direct Reduction of Iron Ores: *K. L. Komarek*, New York University.

The R-N Process involves the direct reduction of iron ores under controlled conditions of temperature and atmosphere using solid carbon fuels. The reaction is carried out in a rotary kiln at temperatures between 1800° and 2000°F, below the melting point of any of the reactants or products. When phosphorus bearing ores are used, the metallic end product will contain varying amounts of phosphorus, depending of the nature of the ore. Based on thermodynamic calculations, an attempt is made to predict the behavior of phosphorus in iron ores.

Changes in the standard free energy of various reactions and partial pressures of various substances under different conditions were calculated. Thermodynamic data of the principal reactions are compared and an explanation for the erratic behavior of phosphorus bearing iron ores is given. The mechanism of these reactions is discussed and it is shown that the problem is essentially thermodynamic and not kinetic in nature.

Whenever phosphorus is present as iron-phosphate, the phosphate will be reduced to gaseous phosphorus which will react with and diffuse into iron. An estimate of the diffusivity of phosphorus in iron and the partial molar free energy of phosphorus indicates that the conditions for a rapid and complete reaction are favorable. Phosphorus present as calcium or magnesium phosphate is not reduced and not transferred under the conditions of the reduction. The theoretical results are supported by mineralogical and chemical analyses. Methods are discussed to prevent any transfer of phosphorus to the iron phase.

Thermochemical Model of the Blast Furnace: *H. N. Lander, H. W. Meyer*, and *F. D. Delve*, Jones & Laughlin Steel Corp.

An Approach to the Problem of Heat Transfer in the Blast Furnace: *W. H. Ceckler* and *H. N. Lander*, Jones & Laughlin Steel Corp.

EMD
Physical Chemistry of Extractive Metallurgy

(Arranged by EMD Physical Chemistry of Extractive Metallurgy Committee)

9:30 am Sheraton-Atlantic Hotel Colonial Room

Chairmen:

W. L. Brytzuk, American Metal Climax Inc.
A. W. Schlechten, Missouri School of Mines

Panel Discussion—Current Status of the Application of Physical Chemistry in Research and Development in Extractive Metallurgy:

1. Trends in the Teaching of Physical Chemistry to Students of Extractive Metallurgy.

Participants: *H. H. Kellogg*, Columbia University
F. A. Forward, University of British Columbia

2. Developments in the Use of Physical Chemistry and Physical Chemists in Metallurgical Process and Product Research and Development.

Participants: *E. R. Marble, Jr.*, American Smelting and Refining Co.
F. J. Shortsleeve, Union Carbide Metals Co.

EMD Hydrometallurgy

(Arranged by EMD Hydrometallurgy Committee)

9:30 am Sheraton-Atlantic Hotel Green Room

Chairmen:
J. T. Sherman, U. S. Atomic Energy Commission
R. C. Peterson, Newmont Explorations Limited

Panel Discussion on Relative Aspects and Condition for Acid and/or Carbonate Circuits for Uranium Recovery:

Panel Members: *Clyde Osborne*, Homestake-New Mexico Partners
Dale Matthews, Anaconda Co.
James Owen, Phillips Petroleum Co.
H. L. Hazen, H. L. Hazen, Inc.
Wayne C. Hazen, Kerr-McGee Oil Industries, Inc.

Moderator: *W. L. Lennemann*

Leach-Precipitation-Flotation Method of Concentration at Miami Copper Company: *J. J. Bean*, Miami Copper Co.

Leaching of Waste Dumps at the Chino Mines Division of the Kennecott Copper Corporation: *W. E. Adkins*, Chino Mines Division, Kennecott Copper Corp.

All-Institute Welcoming Luncheon

12:00 m Statler Hilton Hotel Grand Ballroom

Howard C. Pyle, President, AIME, Presiding

IMD
Metallurgy in the Navy—Requirements, Application, and Research

2:00 pm Sheraton-Atlantic Hotel Ballroom

Introductory Remarks: *Rear Admiral R. Bennett*, USN, Chief of Naval Research

Overall Navy Metallurgy Program: *J. J. Harwood*, Office of Naval Research.

Technical Session: Navy Materials Research and Development Highlights.

Chairman: *N. E. Promisel*, Director of the Materials Division, Bureau of Naval Weapons.

Refractory Metals: *T. F. Kearns*, Bureau of Naval Weapons.

Thermoelectric Materials: *B. D. Rosenbaum*, Bureau of Ships.

Semiconductors: *W. W. Scanlon*, Naval Ordnance Laboratory.

Crack Initiation and Propagation:
V. E. Srawley and *G. R. Irwin*, Naval Research Laboratory

Effects of Radiation on Magnetic Materials: *E. I. Salkovitz*, Naval Research Laboratory

Comment and Discussion Period

ISD Fundamental Studies

2:30 pm Sheraton-Atlantic Hotel Winter Garden

Chairmen:
T. Rosenqvist, Massachusetts Institute of Technology
J. C. Fulton, Allegheny Ludlum Steel Corp.

Solubility of Nitrogen in Liquid Iron Alloys I. Thermodynamics: *R. D. Pehlke*, and *J. F. Elliott*, Massachusetts Institute of Technology

Activity of Tin in Iron-Tin-Carbon Alloys: *R. Shields* and *T. B. King*, Massachusetts Institute of Technology

Self Diffusion of Aluminum in CaO-A_2O_3-SiO_2 Slags: *J. Henderson*, *Ling Yang*, and *Gerhard Derge*, Carnegie Institute of Technology

Effect of Basicity on H_2O Solubility in Silicate Melts: *J. Uys*, Allegheny Ludlum Steel Corp., and *T. B. King*, Massachusetts Institute of Technology

Diffusion of Oxygen in a CaO-Al_2O_3-SiO_2 Slag: *P. J. Koros*, Jones & Laughlin Steel Corp., and *T. B. King*, Massachusetts Institute of Technology

Solubility of Oxygen in Delta Iron: *E. S. Tankins* and *N. A. Gokcen*, University of Pennsylvania

Thermodynamic Properties of Sulphur in Liquid Iron, Cobalt, and Nickel: *M. R. Baren* and *N. A. Gokcen*, University of Pennsylvania.

Further Investigation on Desulphurization of Carbon Saturated Iron with Applied Electric Current: *M. Ohtani* and *N. A. Gokcen*.

EMD
International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt

General

2:30 pm Sheraton-Atlantic Hotel Colonial Room

Chairmen:
J. Bruce Clemmer, U. S. Bureau of Mines
R. C. Hills, Freeport Nickel Co.

Fluid-Bed Roasting—Principles and Practice: *R. B. Thompson*, Dorr-Oliver Inc., and *G. Roesner*, Lurgi Gesellschaft, Frankfort-am-Main, Germany.

Treatment of Copper-Nickel Matte for Metals Separation and Recovery: *Kelvin Sproule*, The International Nickel Co., *G. A. Harcourt*, and *L. S. Renzoni*, The International Nickel Co. of Canada, Ltd.

Cobalt-Nickel Separation Through Volatilization of Certain Organic Compounds: *P. G. Grimes*, Allis-Chalmers Research Laboratories

Cobalt-Nickel Separation by Solvent Extraction: *J. E. Magner*, Dow Chemical Co.

MONDAY, FEBRUARY 15, PM

EMD — Electrolytic Processes

(Arranged by EMD Electrolytic Processes Committee)

2:30 pm — Sheraton-Atlantic Hotel — Green Room

Chairmen:

J. L. Wyatt, Booz, Allen, and Hamilton
F. H. Buttner, Union Carbide Metals Co.

A Basket-Cathode Electrolytic Cell for the Production of Titanium Metal: *W. R. Opie* and *O. W. Moles*, Titanium Division, National Lead Co.

Operation of a 10,000-Ampere Fused Salt Cell and Recovery of Electro-Refined Titanium: *D. H. Baker*, U. S. Bureau of Mines.

High-Purity Electrolytic Chromium: *M. J. Ferrante, P. C. Good, F. E. Block*, and *D. H. Yee*, U. S. Bureau of Mines.

Factors in the Electrowinning of Higher Purity Ingot Cerium from Molten Salts: *B. Porter, E. S. Shedd, C. Wyche, J. D. Marchant*, and *R. G. Knickerbocker*, U. S. Bureau of Mines.

Electrowinning of any metal from a molten medium always depends on a successful combination of many factors, such as the materials of construction of the cell and the electrodes, the composition of the bath, its chemical stability, volatility, melting point, electrical resistivity, solvent power for the feed and the product metal, the properties of the metal to be made. Cerium, being extremely reactive to air, moisture, carbon monoxide, carbon dioxide, carbonaceous solids, most metals, and fused fluoride salts, imposes added difficulties in the design of any electrowinning cell, particularly when higher purity ingot cerium is the objective. Based on the experimental results obtained at the Reno Metallurgy Research Center of the USBM, an evaluation of several critical factors is presented, that is, the formation of molecular oxygen and the presence of more than one valence state of cerium in the bath.

Electrowinning of Tungsten and Molybdenum from Scheelite: *J. B. Zadra* and *J. M. Gomes*, U. S. Bureau of Mines.

All-Institute Pre-Smoker Social Hour

6:00 pm — Statler Hilton Hotel — Sky Top and Penn Top

All-Institute Dinner-Smoker

8:00 pm — Statler Hilton Hotel — Grand Ballroom

TUESDAY, FEBRUARY 16, AM

ISD — Iron and Steelmaking

9:00 am — Sheraton-Atlantic Hotel — Ballroom

Chairmen:

F. C. Langenberg, Crucible Steel Co. of America.
C. W. Sherman, Jones & Laughlin Steel Corp.

Production of Iron from a Silicious Ore by a Two-Step Electric Smelting Process: *G. E. Viens, R. A. Campbell, G. V. Sirianni, G. N. Banks*, and *R. R. Rogers*, Canadian Department of Mines and Technical Survey, Ottawa, Ontario, Canada.

Purification of Steelmaking Fumes: *L. Septier* and *P. Leroy*, Institut de Recherches de la Siderurgie Francaise, St. Germain-en-Laye, France.

Effect of Oxygen Input on Basic Open Hearth Steelmaking: *A. L. Hodge*, and *C. S. Arnold*, Linde Co., Div. of Union Carbide Corp.

EMD — International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt—Fuel-Fired Smelting and Converting

9:00 am — Sheraton-Atlantic Hotel — Colonial Room

Chairmen:

A. C. Richardson, Battelle Memorial Institute
R. J. Stevens, Kennecott Copper Corp.

Smelting Practice at Noranda and Gaspe: *J. N. Anderson*, Noranda Mines, Ltd.

Smelting Practices of Phelps Dodge in Arizona: *M. G. Fowler*, Phelps Dodge Corp.

Certain Limiting Factors in the Design and Operation of Pierce-Smith Converters: *W. J. de Villiers, R. C. Bohme, N. Gibson*, and *W. A. Kealy*, Rhokana Corp., Ltd., Northern Rhodesia.

Converter Practice at Chino Mines Division, Kennecott Copper Corp.: *M. K. Nicholson, P. L. Lockridge*, and *G. C. Beals*, Kennecott Copper Corp.

EMD — Refractories

(Arranged by EMD Refractories Committee)

9:00 am — Sheraton-Atlantic Hotel — Green Room

Chairmen:

A. E. Fitzgerald, General Refractories Co.
H. R. Hanley, School of Mines and Metallurgy

Progress in Development of Refractories for Aluminum Furnaces: *J. L. Dolph* and *C. H. Schweinsberg*, Harbison-Walker Refractories Co.

Refractory Practice at the El Paso Refinery of Phelps Dodge Refining Corp.: *N. R. Alston*, Phelps Dodge Refining Corp.

Observations on Two Castables for Aluminum Remelt Furnaces: *F. C. Steimke, Jr.*, and *C. T. Foster*, Walsh Refractories Corp.

Billet Casting Operations at the Reading Metals Corporation: *E. J. Clugston, Jr.*, Reading Metals Refining Corp.

Suspended Silica Roof Practice at Tacoma: *M. L. Plass*, American Smelting and Refining Co.

IMD — Diffusion

(Based on Submission of Research Abstracts)

9:00 am — Sheraton-Atlantic Hotel — Red Room

Chairmen:

L. L. Seigle, Sylvania Electric Products, Inc.
A. S. Nowick, International Business Machines

Self-Diffusion in Gamma Uranium: *S. J. Rothman, L. T. Lloyd*, and *A. L. Harkness*, Argonne National Laboratory

Self-diffusion in gamma uranium has been measured using a tracer isotope, the sectioning technique, and mass-spectrographic analysis.

The diffusion samples were prepared by depositing by cathodic sputtering a thin layer of U^{235} on a piece of uranium containing 0.0343 pct U^{235}, which had previously been cleaned by cathodic sputtering. After annealing, the samples were sectioned, and the U^{235} concentration of each section was determined mass-spectrographically. In all runs except one, straight-line plots of log c *vs.* x^2 were obtained, where c is the concentration of the in-diffused U^{235}, and x the distance of the center of the section from the original interface. Diffusion coefficients calculated from such plots yielded an Arrhenius equation:

$$D = 2.33 \times 10^{-5} \exp(-28{,}500/RT) \text{ sq cm per sec.}$$

These paratmeters, which are far from what is expected on the basis of the melting point of uranium and of present-day theories of diffusion are discussed in the terms of diffusion mechanisms.

Diffusion of Hydrogen in Plastically Deformed Iron: *M. L. Hill*, Westinghouse Electric Corp.

Specimens of a vacuum melted iron, charged with about 12 ppm of hydrogen, were deformed in simple tension and the non-steady evolution of the contained hydrogen was measured at temperatures from 43° to 94°C. Plastic straining at room temperature caused a decrease in the diffusion coefficient of hydrogen. However, straining at −150°C did not alter the diffusion coefficient significantly. These results are interpreted as an experimental confirmation of an earlier conclusion, derived by Heller from theoretical considerations of hydrogen yield point phenomena, that hydrogen does not interact with dislocations at temperatures near and above room temperature.

Diffusivity of Helium Through Aluminum: *G. T. Murray* and *G. Pincus*, Materials Research Corp.

The diffusivity of helium through aluminum has been measured in the temperature range 350° to 550°C by two different techniques. In the first method, helium is introduced into the aluminum by ionization of helium gas and simultaneous bombardment of an aluminum sheet cathode under a 500 v dc potential. Two such helium charged strips are bonded to form a diffusion sandwich such that the helium is contained within a thin center section. The gas is subsequently allowed to escape from the sandwich during a diffusion anneal. Diffusivities measured in this manner exhibit the expected temperature dependency.

In the second technique helium is introduced homogeneously into an aluminum base lithium alloy by the transmutation of Li^6 atoms during neutron irradiation. The gas subsequently diffuses out of the cylindrical specimen during the diffusion anneal. The measured diffusivities by this technique do not vary with temperature in the expected fashion and also appear to vary with the specimen diameter. It is believed that gas bubble formation during the diffusion anneal may account for this behavior. The absence or presence of such bubbles could depend on the helium content and distribution. The total gas content in the latter technique is much higher than in the former method where the helium diffuses outward through relatively helium-free material.

Anomalous Kirkendall Effect in the Cadmium-Magnesium System: *D. J. Schmatz*, *H. A. Domian* and *H. I. Aaronson*, Ford Motor Co.

Previous investigations of the Kirkendall Effect in binary alloy systems have shown that markers placed in the weld interface will normally migrate toward that side of the diffsion couple which contains the largest proportion of the lower melting element. Paxton and co-workers have recently reported that this rule is not obeyed in the Fe-Cr system, and have suggested that chromium may diffuse by means of a ring mechanism. During the present study, of diffusion in the cadmium-magnesium system, another violation of this rule was found: tungsten markers placed at the weld interfaces of Mg/Cd/Mg diffsion couples move toward the magnesium components of these couples. Further, the rates of marker movement appear to be the highest observed to date. During an anneal of 21 days at 315°C, for example, the markers were displaced 29 mils toward each of the magnesium components. Corrections of the marker movement data for the effects of an appreciable tendency of the c-axes to be aligned perpendicular to the diffusion direction and for the dependence of the lattice parameters upon composition were found to be relatively small. These results will be discussed in terms of the possible operation of an interstitialcy mechanism for the diffusion of a small proportion of the magnesium atoms.

Although inclusions (presumably oxides) were observed in both the cadmium and the magnesium components of the diffusion couples, porosity did not appear within the bulk of either component. Porosity sometimes developed, however, at the tungsten marker wires. When the amount of porosity at the wires was appreciable, the layer of oxide particles at the weld interface moved considerably further into the magnesium than the wires. As evaluated on a plot of marker movement vs (diffusion time)$^{1/2}$, the oxide particles permitted substantially more consistent, and probably more accurate measurements to be made of the Kirkendall Effect than did the tungsten wires.

Measurement of the Surface—Self-Diffusion Coefficient of Copper by the Thermal Grooving Technique: *N. A. Gjostein*, Thompson Ramo Wooldridge, Inc.

Interferograms taken with a Zeiss Interference Microscope were used to measure the thermal groove width w as a function of annealing time t at several different temperatures. Plots of log w vs log t for three copper bicrystals, containing [001] tilt boundaries with misorientations of 16, 19, and 22°, respectively, gave straight lines of slope ¼ for temperatures less than 825°C. This indicates that the relation, $w = k\,t^{1/4}$, derived by Mullins for the case where matter is transported by surface diffusion, is obeyed in this temperature range. Above 825°C, however, the slope was found to have a value between ¼ and 1/3, suggesting that volume diffusion was contributing to formation of the groove. When the contribution to w from volume diffusion was subtracted out, agreement with the surface diffusion time law was obtained.

The Mullins theory was used to calculate the surface-self-diffusion coefficient of copper D_s, for various temperatures in the range 720° to 1070°C from intercepts of log w vs log t plots. The variation of D_s with temperature can be expressed in the form

$$D_s = 6.5 \times 10^2 \exp\left[\frac{-40{,}800}{RT}\right]$$

The implications of such a large activation energy will be discussed in terms of the possibility that chemisorbed impurities on the surface may alter the temperature variation of D_s.

TUESDAY, FEBRUARY 16, AM

Oxidation Mechanism of High Purity Nickel: *J. A. Sartell* and *C. H. Li*, Minneapolis-Honeywell Regulator Co.

An investigation of the oxidation mechanism of high-purity (99.999 + pct) nickel in the temperature range from 800° to 1200°C has been carried out. Inert marker, X-ray diffraction, and metallographic techniques as well as gravimetric data were used.

The results of the gravimetric studies were in good agreement with those reported elsewhere, but in contrast to the idea that only one oxide layer is formed it was found that the scale consists of two distinct oxide layers. Under polarized light the inner layer was seen to be green and fine-grained while the outer layer was dark gray and coarse-grained. The inert markers were found to lie at the interface between the two oxide layers. Examination of the inner and outer surfaces of the oxide scale by X-ray diffraction revealed similar diffraction patterns, the peaks of which occurred at slightly different Bragg angles.

In the light of this investigation the oxidation mechanism previously proposed for nickel must be modified. A tentative mechanism based on these observations will be presented.

IMD Orientation and Textures

(Based on Submission of Research Abstracts)

9:00 am Sheraton-Atlantic Hotel Blue Room

Chairmen:

J. P. Nielsen, New York University

B. D. Cullity, University of Notre Dame

Orientation Distribution of the Surface Plane From Surface Energy Induced Secondary Recrystallization (in Silicon-Iron Sheets): *J. J. Kramer* and *K. Foster*, Westinghouse Electric Corp.

A study was made of the orientation distribution of the surface plane in cube-oriented silicon-iron sheets obtained by a secondary recrystallization process. It can be shown that the relatively low surface energy of the cube plane is important in the formation of this cube-oriented structure by secondary recrystallization. An examination of sheets made by this process indicates that grains whose surface planes deviate slightly from a {100} plane can also grow as secondary grains. For this to occur, these grains must also have a significantly lower surface energy than the matrix grains whose surfaces lie far from a cube plane. The variation of the surface energy with deviations in orientation from the cube plane is discussed in terms of the atomic topography of the surface and the thermal etching that can occur on the sheet surface. These two factors can account for the low surface energy of crystal planes deviating slightly from cube (to about 15°). Factors which would tend to influence the calculated surface energies and thus the growth of deviating cube grains are discussed qualitatively (i.e. the kinetics of thermal etching and curvature in the sheet surface). An X-ray analysis of the surface orientation of a number of secondary cube grains selected randomly from various sheets is presented to show the distribution of orientations that can be expected.

Observations on Oxide Particles on Surfaces of High-Purity Silicon Iron Sheet: *J. L. Walter* and *C. G. Dunn*, General Electric Co.

The pattern and number of oxide particles per unit area of surface that form during slightly oxidizing anneals near 1200°C have been studied using high-purity silicon iron sheet. The number of oxide particles per unit area depends on crystal orientation, in agreement with published results for other material. The patterns of the oxides on the surface also depends on crystal orientation, particularly when thermal striations appear on the surface between the oxides. In areas swept by migrating grain boundaries, however, the pattern of oxides may be altered by interaction effects. For example, an increase in size of oxide particles may occur for oxides positioned slightly in advance of a migrating grain boundary. In other instances oxide particles may move along with a boundary for distances of several microns. It is suggested that surface discontinuities are important both in the nucleation of oxides and in the repositioning of oxides after they are formed.

Dependence of Wire Texture in F. C. C. Metals on Stacking Fault Energy: *Norman Brown*, University of Pennsylvania.

The wire texture in FCC is in general a double texture [100] and [111]. A survey of the percent of each texture in the various metals shows that the metals with higher stacking fault energy have more [111] texture.

The new contributions to the theory of wire textures are: 1.) The [111] is shown to be more likely than the [100] texture using a probability argument. 2.) The conversion from [100] to the more probable [111] texture takes place by cross-slip. 3.) The rate of cross-slip, as pointed out by Seeger, depends greatly on the stacking fault energy.

A comparison of existing measurements of the stacking fault energy of a metal with the amount of [111] texture shows more than a fortuitous correspondence.

TUESDAY, FEBRUARY 16, AM

Evolution of Textures in F. C. C. Metals. Part II—Alloys of Copper With Phosphorus, Arsenic and Antimony: *R. H. Richman* and *Y. C. Liu*, Ford Motor Co.

The deformation and recrystallization textures of copper alloyed with phosphorus, arsenic or antimony have been examined thoroughly using the procedures previously described. Transition from the copper type to the 70:30 brass type of deformation texture is initiated by approximately 0.5 at. pct P, 0.4 at. pct As or 0.3 at. pct Sb. Completion of the textural transition has been observed only in Cu-As alloys.

The general pattern for the development of individual recrystallization components in the present alloys resembles that observed in studies of Cu-Zn, Cu-Ge, and Cu-Sn alloys, but with definite differences in detail. The {358} <523>, {113} <211> and {012} <001> type of recrystallization components appear in alloys that demonstrate a copper type of deformation texture, but, unlike the past studies, diminish or disappear in the composition range at which the deformation transition begins. As the deformation transition procedes with increasing solute content, a new generation of previously unreported recrystallization components evolves.

Although the major components in the new generation of recrystallization textures do not have the same ideal orientations in all three alloy series, they nevertheless possess the common characteristic of a (110) plane parallel to the plane of the sheet. An approximate description of the orientations is {110} <112> ± 15°, {110} <112> ± 24°, and {110} <001> in Cu-P, Cu-As and Cu-Sb alloys, respectively. All of these recrystallization components exhibit relatively high intensities, higher for instance than any components appearing in Cu-Ge or Cu-Sn alloys. In addition to the (110)-components, a strong component with Miller indices close to {113} <332> was observed in each alloy series.

Annealing Twins and Coincidence Site Boundaries in High-Purity Lead: *K. T. Aust* and *J. W. Rutter*, General Electric Co.

Fullman and Fisher have advanced the following theory to account for the formation of annealing twins during grain growth. Whenever a grain *A* grows into a matrix of grains *S*, a twin *A'* of grain *A* may form if the energy, γ, of the boundary *A'S* is less than that of the boundary *AS* by an amount which exceeds the energy of the coherent twin boundary *AA'*. The nature of the boundaries *AS* and *A'S*, which leads to the difference in boundary energies required by the Fullman-Fisher relationship, $\gamma_{A'S} + \gamma_{AA'} < \gamma_{AS}$, was not explained by the theory.

The present study deals with the growth of a recrystallized grain into a striated, melt-grown crystal of zone-refined lead containing < 1.5 atom ppm of Sn, Ag or Au. A twin *A'* of the recrystallized grain *A* was sometimes observed to form and propagate into the striated crystal *S*. On several occasions, a twin *A''* of the original twin *A'* was also formed, at a later stage, and grew into the striated crystal. It was found that, in every case where an annealing twin was formed during grain boundary migration, a large-angle random boundary, *AS*, was replaced by a large-angle coincidence boundary of the type discussed by Kronberg and Wilson or by a near-twin boundary, *A'S*. When twinning occurred a second time, the first coincidence-type boundary was replaced by a second one having a higher density of coincidence sites.

The present results provide further support for the Fullman-Fisher theory of annealing twins, and demonstrate the usefulness of interpreting certain large-angle grain boundaries in terms of the coincidence site model.

ISD — Howe Memorial Lecture

11:00 am — Sheraton-Atlantic Hotel — Ballroom

Joseph L. Gillson and *Michael Tenenbaum*, Chairmen

Speaker: *Robert F. Mehl*, Carnegie Institute of Technology

Subject: Commentary on Metallurgy

TUESDAY, FEBRUARY 16, PM

ISD — Annual Luncheon and Business Meeting

12:15 pm — Sheraton-Atlantic Hotel — Winter Garden

Michael Tenenbaum, Chairman, Presiding

Speaker: *Hjalmar W. Johnson*, Vice-President—Planning and Research, Inland Steel Co.

Subject: Midwestern Steelmaking

All-Institute Session

2:30 pm — Statler Hilton Hotel — Grand Ballroom

(Program to be Announced)

All-Institute Annual Business Meeting

4:00 pm — Statler Hilton Hotel — Grand Ballroom

Met. Soc. — Social Hour

6:00 pm — Sheraton-Atlantic Hotel — Winter Garden

Met. Soc. — Annual Dinner

7:00 pm — Sheraton-Atlantic Hotel — Winter Garden

John Chipman, President, Presiding

Presentation of Awards:

Robert W. Hunt Medal to *T. E. Dancy*, *A. T. Sadler*, and *H. N. Lander*

J. E. Johnson, Jr. Award to *Harry Holiday*

Rossiter W. Raymond Memorial Award to *Paul Shewmon*

Special Citation to *John Wulff*

Speaker: *Professor C. Stark Draper*, Head, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology

Subject: Guidance for Spacecraft

All-Institute Informal Dance

9:00 pm — Statler Hilton Hotel — Terrace Ballroom

WEDNESDAY, FEBRUARY 17, AM

IMD-ISD — Solidification I

9:00 am — Sheraton-Atlantic Hotel — Ballroom

(Arranged by ISD Physical Chemistry of Steelmaking Committee in Cooperation with the Institute of Metals Division)

Chairmen:

W. G. Pfann, Bell Telephone Laboratories

F. D. Rosi, Radio Corp. of America

Condensation Coefficients of Silver, Zinc and Cadmium in Growth from the Vapor Phase: *R. A. Rapp*, Max-Planck Institut fur Physikalische Chemie, *J. P. Hirth*, Carnegie Institute of Technology, and *G. M. Pound*, Sheffield University.

Experiments have been performed in which atomic beams of silver, zinc, and cadmium were impinged on substrates of the same metals. A condensation coefficient of unity has been determined for silver deposited from the vapor phase at high fluxes over a temperature range of 45° to 440°C and at residual gas pressures ranging from 10^{-4} to 6 x 10^{-10} mm Hg. Condensation coefficients of unity have been established for Zn at 68°C and Cd at 18°C in ultrahigh vacuum. The adsorption of gaseous impurities at residual gas pressures of 10^{-4} mm Hg did not affect the condensation coefficient of cadmium at 23°C for condensation at high fluxes.

These results are in agreement with the theory of crystal growth proposed originally in various aspects by Volmer and by Langmuir.

On the Structure of Single Crystals Grown From the Melt: *P. E. Doherty* and *R. S. Davis*, Arthur D. Little, Inc.

A study of certain aspects of the structure of aluminum specimens is greatly facilitated if surface pits are formed by the condensation vacancies during cooling from an elevated temperature. In particular, vacancy sinks like sub-boundaries, cavities, and second-phase particles are revealed for macroscopic study by the absence of pits in their vicinity.

This technique has been applied to the structure of aluminum single crystal specimens produced under a wide variety of growth conditions by linear solidification in graphite boats. The influence of solute additions, temperature gradients, and rate of growth on the formation of striations, and other sub-boundaries will be discussed. Observations of the formation of sub-boundaries and shrinkage cavities by the dendritic mode of freezing will be presented and discussed. In addition shrinkage cavities have been observed in the cell walls.

In general the results of this investigation substantiate our present understanding of the solidification process. The observations of pores in the cell boundaries (that have been interpreted as shrinkage cavities) tend to support the thesis that the depth of the liquid layer film that bounds the cells at the solid-liquid interface is considerably greater than that observed from decanting experiments.

Solute Segregation During Dendritic Growth: *F. Weinberg*, Department of Mines and Technical Surveys.

Quantitative measurements of solute segregation during dendritic growth have been made using radioactive tracers as the added solute element. Segregation has been studied in lead and tin with small additions of each of the following solutes: Ag^{110}, Tl^{204}, Zn^{65}, Co^{60}, Ni^{59}, and Sn^{113}.

The technique used was to produce large dendrites of the material being examined in controlled orientation single crystals, as described by Weinberg and Chalmers. The dendrites were cut from the decanted single crystals, then remelted and formed into a standard specimen shape. The activity of this specimen was measured in a suitable counting device and compared to the activity of corresponding specimens made from the melt in which the dendrites had grown.

The results indicate that appreciable solute segregation can occur during dendritic growth. The amount of segregation was found to depend on the particular system being examined, and, in some cases, on the concentration of the solute. Detailed results will be presented and discussed.

In addition to the above measurements, qualitative observations of the solute distribution in dendritically solidified specimens have been made using autoradiographic techniques. This has been done for zinc alloys as well as some of the lead and tin alloys listed above.

On The Growth of Germanium Dendrites: *R. S. Wagner*, Bell Telephone Laboratories.

Growth of germanium crystals from a seeded supercooled melt can be either slow (polyhedral) or very rapid (dendritic) depending on the crystallographic nature of the seed.

It was found that a necessary condition for dendritic growth in germanium is a seed crystal that contains at least two parallel twin planes.

We propose a mechanism for the dendritic growth process and present experimental evidence for it.

Propagation of Germanium Dendrites: *J. W. Faust, Jr., D. R. Hamilton, H. F. John*, and *R. G. Seidensticker*, Westinghouse Electric Corp.

The role of the twin planes in the rapid dendritic propagation of germanium crystals is examined on the basis of corner nucleation. A model is proposed which perpetuates a corner and requires the presence of at least two twin planes. Experimental evidence substantiates the basic tenets of this hypothesis and also indicates that a different mechanism is involved in the lateral growth.

Development of Preferred Crystal Orientation in Cast Silicon-Iron Ingots: *H. J. Fisher* and *J. L. Walter*, General Electric Co.

The development of a preferred crystallographic orientation in cast ingots for the express purpose of producing a particular preferred orientation in thin sheet rolled from such ingots has been investigated. In this study, preferred orientations near (100) [001] were produced in ingots of 3¼ pct Si-Fe.

Ingots having two different types of preferred orientations were produced: 1.) Singly-oriented ingots in which the [001] directions of the crystals were parallel to the longitudinal ingot axis and to the columnar crystal axes, and, 2.) doubly-oriented ingots in which all columnar crystals have the (100) [001] orientation with respect to the sides of the ingot.

Control of the direction of growth of the crystals of the columnar ingots was achieved by removing heat unidirectionally from the bottom of the mold. The (100) [001] orientation in the doubly-oriented ingots was produced by pouring the molten metal on a seed having a predetermined orientation. The seed provided the necessary crystallization sites to control the orientations of the first-forming crystals of the ingot X-ray diffraction analysis showed that the crystals of the ingot had the (100 [001] orientation.

The freezing rates and temperature gradients required to sustain columnar growth were also measured. It was found that even though the freezing rate approached zero, columnar growth tendencies could be sustained as long as the temperature gradient ahead of the solidification front was greater than zero.

WEDNESDAY, FEBRUARY 17, AM

EMD-ISD
International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt—Electric Furnace Smelting

9:00 am Sheraton-Atlantic Hotel Colonial Room

Chairmen:

Paul Queneau, The International Nickel Co. of Canada, Ltd.

A. J. Phillips, American Smelting and Refining Co.

Electric Smelting of Sulfide Ores: *Otto Barth*, Barths Metallurgiska Byra, Stockholm, Sweden.

Utilization of Nickelferous Serpentine: *L. H. Banning*, U. S. Bureau of Mines.

WEDNESDAY, FEBRUARY 17, AM

Production of Ferronickel at Riddle, Oregon: *E. E. Coleman*, Hanna Nickel Smelting Co., and *D. N. Vedensky*, Hanna Mining Co.

Ferro-Nickel Smelter of Doniambo (New Caledonia): C. G. Thurneyssen, J. Szczeniowski, and F. H. Michel, Societé Le Nickel, Paris, France.

EMD
Uranium, Rare Earths, and Minor Metals

(Arranged by EMD Uranium, Rare Earths, and Minor Metals Committee)

9:00 am Sheraton-Atlantic Hotel Green Room

Chairmen:

C. K. McArthur, Utah Construction and Mining Co.

E. C. Van Blarcom, U. S. Atomic Energy Commission

Production of UF_4 from Scrap Leach Liquors: *J. H. Cavendish, S. Cseplo, E. O. Rutenkroger*, and *M. A. DeSesa*, National Lead Co. of Ohio.

Rare Earth Separations by Liquid-Liquid Extraction: *Boyd Weaver* and *F. A. Kappelman*, Union Carbide Nuclear Co.

Mechanical Properties of Pure Rare Earth Metals: *Bernard Love, H. M. Muir*, and *C. G. Kirkpatrick*, Research Chemicals Div., Nuclear Corp. of America.

Separation of Rare Earths by Ion Exchange and Solvent Extraction—A Comparison of Methods: *H. G. Petrow*, Ionics, Inc.

Production of Pure Columbium and Tantalum Oxides by Liquid-Liquid Extraction: *C. W. Carlson* and *R. H. Nielsen*, Wah Chang Corp.

IMD Dislocations I

(Based on Submission of Research Abstracts)

9:00 am Sheraton-Atlantic Hotel Red Room

Chairmen:

E. S. Machlin, Columbia University

R. L. Smith, Michigan College of Mining and Technology.

Evidence for Vacancy Clusters in Quenched Aluminum: *D. Kuhlmann-Wilsdorf*, University of Pennsylvania and *H. G. F. Wilsdorf*, The Franklin Institute.

Aluminum, quenched from temperatures close to its melting point, contains a high density of prismatic dislocation loops due to the condensation of thermal vacencies into collapsed discs. It had been predicted and was subsequently found that such loops should tend to lie parallel to {111} planes and to have hexogonal shapes with sides parallel to <110>. Closer investigation of such quenched-in dislocation loops has revealed (i) that not all the loops are parallel to {111}; (ii) that the loops often arise in clusters with an unexpectedly high proportion of loops with one particular orientation; (iii) that loops are present often in pairs, consisting of two loops of like shape, size and orientation, separated by distances from a few hundred to thousands of Angstroms. These findings are interpreted together with related results in the published literature. It is concluded that about one tenth of all condensed vacencies form voids, undetected with electron microscopes, and that such voids, although to a smaller extent, also exist in furnace cooled specimens. The voids are believed to be responsible for the formation of the tangled and twisted dislocations found in lightly deformed aluminum specimens.

Contribution of Interface Dislocations to Precipitation Hardening: *R. L. Fleischer*, Massachusetts Institute of Technology.

A crystal having two regions of slightly different lattice spacing is considered. In such a crystal, slip causing a displacement along a direction in which the lattice spacing changes value will produce interface dislocations. Because subsequent motion of these interface dislocations would create surfaces of lattice misfit, they are sessile and hence contribute to work hardening. A model based on interface dislocations should therefore describe work hardening in precipitates which have a slip system aligned with an active sys-

tem of the matrix. The model should be applicable not only to coherent precipitates but also to overaged alloys as long as this alignment is preserved.

In order to show that the effect may be considerable, a highly simplified hardening model is proposed, the flow stress being determined by the stress to move a regular dislocation past a fixed interface dislocation. The model predicts a work hardening rate of $G\,\Delta b/b\,8\pi(1-\nu)$. ($G$ = shear modulus; b = original slip vector; Δb = change in slip vector; and ν = Poisson's ratio.) It is suggested that in earlier stages of deformation this result should underestimate the hardening rate but should approximate the average rate. It is further noted that when the model assumed herein in fact applicable, fine slip and homogeneous deformation is to be expected.

The possibility of interface dislocations at free surfaces is also described. In certain cases these dislocations should impede regular dislocations approaching a crystal surface.

Strength and Elastic Properties of an Edge and a Screw Dislocation Wall: *J. C. M. Li*, United States Steel Corp.

A detailed elastic theory calculation reveals the following conclusions regarding the strength and properties of a substructure boundary: (1) an edge dislocation wall is a less effective barrier against a pile-up of dislocations than a screw dislocation wall. Due to the long range stress field of a screw dislocation wall, the stress concentration at a screw dislocation wall created by a pile-up of dislocations is much less than that at an edge dislocation wall; (2) the strength of a finite edge dislocation wall is larger than that of an infinite edge dislocation wall but is only slightly larger than that of a dislocation grid work formed by the same number of dislocations as that in the finite wall uniformly distributed in a square whose side is the same as the height of the wall; (3) the dilatational strain field of a finite edge dislocation wall is such that the flow lines of point imperfections are circular arcs passing through the two ends of the wall. The fact that the positive dilatational regions in the upper half of the wall or the negative dilatational regions in the lower half of the wall are only small loops near the core of the dislocations in the wall indicates that only half of the wall has long range interactions with certain solute atoms. It follows that half of the dislocations in a freshly formed wall may not be easily pinned by point defects; and (4) a screw dislocation wall exerts large local torques on approaching nonparallel dislocations to introduce wiggles in the dislocation lines. Such wiggles contribute to the plastic behavior of a substructure boundary by acting as sources for generating dislocations.

Dislocation Sources in Thin Foils: *H. G. F. Wilsdorf*, The Franklin Institute.

As had been shown earlier, the straining of metal foils (approximately 1000 A thick) in the electron microscope provides a means of studying directly the behavior of dislocations during plastic flow. Much attention has been paid to multiplication processes for dislocations. In polycrystalline specimens of stainless steel the majority of dislocations came from grain and twin boundaries. Also, stress concentrations near precipitates caused the emission of dislocations. Further, it was observed that suitably anchored dislocation lines acted as sources according to the proposed mechanism by Frank and Read. With increasing deformation these sources became more frequent, indicating that they are brought into being through the interaction of dislocations. Finally, prismatic dislocation loops have been seen acting in quenched aluminum foils. This example concludes the experimental evidence for the dislocation sources in metals which had been predicted by theory.

Direct Observation of Dislocations Moving in Strain-Hardened Crystals: *J. J. Gilman* and *W. G. Johnston*, General Electric Co.

It is usually difficult to study the behavior of individual dislocations in strain-hardened crystals because so many dislocations are present that no one of them can be readily singled out for observation. However, in the case of LiF crystals, a procedure has been devised which allows observations to be made of individual dislocations moving in strain-hardened crystals. By taking advantage of the fact that *aged* dislocations etch differently than *fresh* dislocations, it is possible to strain a crystal, age the dislocations, in it, introduce some fresh dislocations, and etch the crystal so that the aged and fresh dislocations can be distinguished from each other. Then stresses can be applied to the crystal in order to produce motion of the fresh dislocations, and their velocities can be measured. The aged dislocations are pinned, so they do not move during these latter stress applications.

In this study dislocation mobilities in undeformed crystals are compared with those in strain-hardened crystals. In this way, it has been established by direct observations that individual dislocations move more slowly in strain-hardened LiF crystals, at a given applied stress, than in undeformed crystals. The stress increment that is needed to give the same dislocation velocity in both crystals, corresponds to the difference between their macroscopic flow stresses.

Existing theories of strain-hardening do not correctly predict the behavior of LiF. Barrier-type theories are ruled out because the distance that a dislocation can move in a strain-hardened crystal does not seem to be limited. Theories of Taylor hardening or of cutting of dislocation forest do not give the observed dependence of strain hardening on dislocation density. It is observed that the strain-hardening increment is proportional to the dislocation density (also to the plastic strain), and the proportionality constant is 3 to 5 dynes per dislocation. The data are consistent with the idea that the hardening is due to defects left in the wakes of moving dislocations. These defects would interfere with the movement of subsequent dislocations on the same or nearly glide planes.

IMD
Phase Transformations and Segregation

(Based on Submission of Research Abstracts)

9:00 am Sheraton-Atlantic Hotel Blue Room

Chairman:

M. B. Bever, Massachusetts Institute of Technology.
J. N. Hobstetter, University of Pennsylvania

Precipitation in Au-Ni Alloys: *E. E. Underwood*, *Morris Cohen*, and *B. L. Averbach*, Massachusetts Institute of Technology.

Rates of growth G, nucleation I, and precipitation P, were determined within the composition and temperature limits of the miscibility gap in the Au-Ni System. Quantitative metallographic methods and electrical resistance measurements were used to follow the course of the predominant grain-boundary reaction.

The curves of P_{max} and I_{max} do not lie along the spinodal, but about 200°C below and somewhat parallel to the top of the miscibility gap. An additional low-temperature peak in I, called I_{max} (*lower*), is found which is not accounted for by any well-known theory, even though double peaks in I have been observed experimentally in the past.

Single maxima in G are seen to occur near 600°C. The coincidence of the temperatures for G_{max} and I_{max} (*upper*) accounts for the maximum obtained in P. I_{max} (*lower*) does not cause a noticeable enhancement of P at low temperatures because G there is too low. However, at about 90 pct transformation, the influence of both peaks in I can be detected as a relative acceleration of the transformation at both the upper and lower temperatures.

Iso-rate contours in both G and P, when superimposed on the phase diagram, show anomalies near 60 at. pct Ni. The significance of these anomalies is discussed in relation to the thermodynamic properties, diffusion data, and mechanical behavior of the system.

Kinetics and Mechanism of the Precipitation of Lithium from Germanium: *J. R. Carter* and *R. A. Swalin*, University of Minnesota.

Using electrical resistivity techniques, the kinetics of the precipitation of lithium from germanium has been investigated. In an attempt to obtain information about the mechanism of nucleation the influence of thermal history and addition of small amounts of impurities on the precipitation kinetics has been investigated.

Preannealing treatments of the base crystals prior to saturation with lithium can have a pronounced effect on the effective concentration of precipitation nuclei. For example, a 2-hr preanneal at 900°C *increases* the concentration of nuclei upon the introduction of lithium by an order of magnitude regardless of cooling rate from the annealing temperature, whereas a preanneal at 750°C has virtually no effect.

Impurity additions also can have a pronounced effect. Addition of 10^{15} copper atoms per cu cm concurrent with saturation with 10^{17} lithium atoms per cu cm results in an order of magnitude *decrease* in the effective concentration of nuclei for precipitation. On the other hand additions of oxygen are found to markedly *increase* the concentration of nuclei.

The shape of the log fraction precipitated versus time curve is in general agreement with the theory of Ham for the growth of precipitate particles when the lithium saturation temperature is high but pronounced transient effects occur (involving 20 pct of the process) when the lithium saturation temperature is low.

The relation of the above observations to the mechanism of nucleation of the process is discussed.

Kinetics of Martensitic Transformations in 49 At. Pct. Cd Gold-Cadmium Alloys: *J. A. Mullendore*, *D. S. Lieberman*, and *T. A. Read*, University of Illinois.

Most of the previous work on the cubic to tetragonal transformation in 49 at. pct Cd gold-cadmium alloys has been concerned with the crystallographic relationships between the large domains of fine twins and the parent phase. The present investigation was undertaken to study the kinetics of the transformations in this alloy, particularly the isothermal transfromation. It was first observed that the commonly seen transformation by the growth of a few large domains of twins is not really athermal at all, as is the cubic to orthorhombic transformation in alloys of slightly lower cadmium content. This normal *athermal* transformation over a transition region (M_s to M_f) of about one degree is found for only a narrow range of cooling rates; faster cooling to temperatures below M_s can not be followed by the transformation and isothermal growth of the large domains results while slower rates result in complete transformation within about 0.1°C. However, for all rates faster than these latter ones, the final amount of martensite at any temperature between M_s and M_f depends only on the temperature.

A completely different microstructure was revealed in the detailed studies of the isothermal transformations above Ms. Here the transformation is found to take place by the formation of many small plates in manner similar that observed in Fe alloys. An activation energy based on the reaction path model was calculated to be about 25 Kcal per mol. Observations were also made on the reverse isothermal tetragonal to cubic transformations and the calculated activation energy was the same. The isothermal transformations appear to be primarily nucleation controlled while the *athermal* kinetics are predominantly growth controlled. In spite of the lack of similarity in the microstructures, the crystal structures (as shown by X-ray diffraction) and the electrical resistivities are the same. Relative free energy curves, stabilization effects and analysis of the kinetics will be discussed.

Segregation of Sulphur to Austenite Grain Boundaries:
R. G. Ward, Carnegie Institute of Technology, and *A. G. Franklin*, University of Sheffield.

By means of quantitative autoradiography, the distribution of S35 in austenitic iron has been determined. After equilibration of the iron-sulfide alloys in the austenitic range and fast cooling to room temperature, the sulfur is found to be present uniformly distributed within the grains, as sulfide particles at the grain boundaries and also as segregation at metallographically featureless grain boundaries. A wide range in the concentration of sulfur at segregated grain boundaries occurs in any specimen, presumably indicating a strong dependence of segregation on relative grain orientation.

From a consideration of the maximum segregation of sulfur observed in specimens equilibrated at 1000°, 1100°, and 1200°C, an activated energy of 25,000 ±5,000 cal was obtained for the segregation process.

Sulfur Segregation at Alpha-Iron Grain Boundaries, I:
N. G. Ainslie, R. E. Hoffman, and *A. U. Seybolt*, General Electric Co.

Radioactive sulfur has been introduced simultaneously into single crystal and polycrystal specimens of high-purity α-iron by reaction with H_2S. After lengthy annealing and rapid quenching, the polycrystals are found to contain 50 to 100 pct more sulfur than the single crystals, and the excess sulfur in the polycrystals is found to be concentrated at the grain boundaries. All available evidence indicates that the sulfur was in solid solution at the equilibration temperature, although the amount of sulfur segregated at the boundaries is much greater than can be accounted for on the basis of equilibrium adsorption.

Sulfur Segregation at Alpha-Iron Grain Boundaries, II:
N. G. Ainslie, V. A. Phillips, and *David Turnbull*, General Electric Co.

Alpha-iron grain boundaries containing large excesses of adsorbed sulfur were examined using transmission electron microscopy. The study revealed that the grain boundaries of the sulfurized iron were commonly associated with very high density dislocation networks that could extend several microns into the bulk of the grains. The dense networks were not observed in pure, sulfur-free iron. The networks are thought to form when the sulfur, having first entered the specimens by preferential diffusion along grain boundaries, diffuses from the grain boundaries laterally into the grains. The sulfur, which diffuses in iron as a substitutional element about 30 times faster than iron self-diffuses, establishes a diverging vacancy flux toward the boundaries. The result is a vacancy undersaturation in the neighborhood of the boundaries that accounts, it is believed, for the high dislocation density; the vacancy undersaturation causes dislocation multiplication by *down-climb*.

The abnormal segregation of sulfur in the vicinity of α-iron grain boundaries is explained if it is assumed that sulfur is adsorbed by dislocations in the boundary networks. The possible effects of these grain boundary networks on certain other metallurgical phenomena are considered.

MBD-IMD-EMD
Basic Science Symposium on Surface Phenomena for Mineral, Ceramic, and Metallurgical Systems

(Arranged by Basic Science Committee of Minerals Beneficiation Division)

9:00 am Statler Hilton Hotel Sky Top

Chairmen:

P. L. de Bruyn, Massachusetts Institute of Technology

R. J. Charles, General Electric Co.

Elementary Concepts of Surface Energy and Their Applications in the Metallurgical Industry:
C. S. Smith, University of Chicago.

This introductory talk will cover the nature of surfaces and interfaces, interatomic forces that give rise to surface energy and surface tension, the principles of surface energy equilibrium, and some applications of surface chemistry and surface physics to various mineral industry problems.

The Influence of Solutes on Interfacial Tensions and on the Contact Angle:
J. Th. G. Overbeek, University of Southern California, and *P. L. de Bruyn*, Massachusetts Institute of Technology.

According to the Young equation, $\gamma_{SG} = \gamma_{SL} + \gamma_{LG}\cos\theta$, the equilibrium contact angle depends on the values of the three interfacial tensions involved. A solute promotes wetting, i.e. a decrease of contact angle if it decreases. γ_{LG} and/or γ_{SL} or if it increases γ_{SG}. Dewetting, the important step in flotation, is promoted if the solute increases γ_{LG} and/or γ_{SL} or decreases γ_{SG}. Most solutes used for wetting or dewetting are positively adsorbed at all interfaces involved and consequently according to the Gibbs equation lower the interfacial tensions. Wetting is therefore expected to occur if γ_{LG} and γ_{SL} are more affected by the solute than γ_{SG}. Dewetting on the other hand demands a greater decrease of γ_{SG} than that of γ_{SL} (and of γ_{LG}).

Wetting, depending mainly on a lowering of γ_{LG} is expected to be rather unspecific; dewetting, however, may be quite specific, because it depends mainly on the difference of the changes in γ_{SG} and γ_{SL}.

In dewetting it is not necessary that the solute is adsorbed to a higher amount on the solid-gas than on the liquid-gas interface. It is sufficient that the adsorption at the solid-gas interface starts at a lower activity (≈ concentration) of the solute than at the solid-liquid interface. This again is a direct consequence of the Gibbs equation, which for a single solute may be put in the form,

$$\Delta\gamma = -\int \Gamma d\mu = -\int RT\Gamma \, d\log c$$

where Γ is the adsorption in moles per sq cm and μ the chemical potential of the solute.

In flotation the collector will be more easily adsorbed at the solid-gas interface because as a partially hydrophobic substance it is pushed away from the water. The specific factor, which allows the collector to become attached rather to one solid than to another one, may be either a chemical affinity (xanthates for sulfide minerals) or of an electrical nature (influence of pH, isoelectric point, inorganic ions etc.).

Kinetics of Wetting and Surface Energies of Solid Metals:
C. M. Adams, Massachusetts Institute of Technology.

Detailed thermodynamic consideration of equilibria involved in the partial or complete wetting of solid surfaces by liquids has received much attention in the literature, both for metallic and non-metallic systems, but much less attention has been given the kinetic factors which govern the rate with which a liquid can wet a solid. Systems of interest are: (1) liquid spreading upon a solid surface with amplification of the liquid-vapor and liquid-solid interfacial areas. (2) liquid flow through a capillary with work being done by the exchange or solid-vapor surface for liquid-solid surface, without changing the magnitude of the small, liquid-vapor surface area.

The basic, familiar equilibria governing the tendency for wetting can be expressed in terms of four inequalities:

A.	Complete non wetting	$\gamma_{ls} > \gamma_{sv} + \gamma_{lv}$
B.	Partial wetting	$\gamma_{sv} + \gamma_{lv} > \gamma_{ls} > \gamma_{sv}$
C.	Wetting	$\gamma_{lv} + \gamma_{ls} > \gamma_{sv} > \gamma_{ls}$
D.	Spreading	$\gamma_{sv} > \gamma_{lv} + \gamma_{ls}$.

where γ_{ls}, γ_{sv}, γ_{lv} refer to the surface tension of the liquid-solid, solid-vapor and liquid-vapor interfaces. In many systems involving contact between liquid and solid metals at high temperature, the situation which prevails is that represented by inequality *D*, spreading, although metallic systems exhibiting the wetting behavior reflected by inequality *C* are not uncommon (i.e. eg. mercury on steel at room temperature).

When a liquid and solid accommodate one another in such a way that the liquid-solid interfacial energy is extremely low compared to either the liquid-vapor or gas-vapor interfacial energies, complete spreading often obtains, since solid-vapor interfacial energies are generally somewhat higher than liquid-vapor interfacial energies. The kinetics by which a liquid metal advances over a solid metal surface have been analysed for capillary flow, and, to some extent, for liquid spreading freely on an unbounded, plain solid surface. Both are of importance in systems encountered in brazing, and the two mechanisms (capillary flow and free spreading) may, in some circumstances, compete. Not only is the kinetic system complicated by viscous flow and irreversible energy changes, but the pertinent interfacial energies may exhibit time-dependent characteristics as well. The establishment of static equilibrium contact angles often involves vapor transport from the liquid phase to the solid surface, with the result that the solid surface energy is materially influenced, usually lowered. In spreading at high velocities, vapor transport effects may be partially or completely inhibited. Thus, for example, certain lead-tin solders will initially wet a copper-base alloy surface, exhibiting complete spreading, and subsequently withdraw into droplets, exhibiting the wetting condition reflected by inequality *C*.

The contact angle, which prevails during the advance of liquid over a solid surface, has been investigated for very low rates of travel, under conditions where wetting (but not spreading) obtains. The fact that the angle of contact between a liquid and solid depends on the direction of motion of the liquid, *hysteresis* has been studied by Wright for the wetting of steel by liquid mercury. In general, the advancing contact angle is greater than the receding contact angle with the equilibrium value lying between the two extremes, but very near the advancing contact angle at low rates of travel. However, in systems of interest in brazing, rates of spreading of liquid metals may be the order of several inches per minute; contact angles under these conditions are not known.

When a liquid-solid system conforming to inequality *D*, complete spreading, is considered, the rate with which a liquid will freely spread on a solid surface is proportional to the *thickness* of the liquid film, inversely proportional to the liquid-vapor surface area of the film, and inversely proportional to the viscosity. The constant of proportionality embodies all three interfacial energies and has been referred to as the spreading pressure ($\gamma_{sv} - \gamma_{ls} - \gamma_{lv}$). Under capillary flow conditions the rate with which the liquid advances is governed by viscous resistance to laminar flow through the capillary, and the velocity (with the contact angle equal to

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zero) is proportional to the liquid-vapor surface energy. For different metallurgical systems and different capillary dimensions, it is possible for the spreading velocity to exceed the capillary flow velocity, a situation which can create problems in brazing.

Surface films influence wetting kinetics primarily by modifying (increasing) effective liquid-solid interfacial energies. A complete barrier film can have the effect of generating two complete surfaces at the liquid metal "interface" such that

$$\gamma_{1s} \cong \gamma_{1v} + \gamma_{sv},$$

with complete non-wetting the result. Any influence which increases the liquid-solid interfacial energy without violating inequality *D*, (spreading) will have the effect of reducing the spreading rate without influencing the rate of capillary flow. If the interfacial energy becomes still higher such that inequality *C* prevails, capillary flow will still take place, but the rate of free spreading will be zero.

Some Aspects of the Foaming of Fused Silicates: *C. F. Cooper* and *C. L. McCabe*, Carnegie Institute of Technology.

In earlier work by one of us (C. F. Cooper) experiments were carried out on the foam stability, under reducing conditions, of synthetic CaO-SiO_2 slags containing various oxide additions. In the present investigation of several slags foam stability was measured in oxidizing atmospheres. An experiment consisted simply of making a froth from the melt under examination by the passage of gas through a jet immersed under the surface of the slag and of measuring the length of time for the froth to decompose from a higher level to a lower one, the levels determined by pointers. The apparatus follows the design of Cooper and Kitchener, except that the crucible material was platinum or iron and argon was used to produce the froth.

The work of Cooper and Kitchener had established that additions of the acidic oxides, P_2O_5 and B_2O_3, to acid calcium silicate melts caused considerable foam stability. The present investigation has established that the addition of 1 mol pct of the basic oxides Na_2O, SrO, and MgO to acid calcium silicate melts has no stabilizing effect, whereas the addition of 1 mol pct of Fe_2O_3 and Cr_2O_3 caused considerable foam stability. The conclusion is that acid oxides and some amphoteric oxides cause foam stability in acid silicate melts. This conclusion is discussed in terms of the surface tensions of the oxides added and their ability as network formers. To see if there was some generality to these observations, a melt of $Na_4B_2O_7$ was prepared and was found to have slight foam stability in the region 750° to 900°C. Addition of 1 mol pct P_2O_5 resulted in a considerable increase in foam stability and extended the foaming range to 1000°C. Sufficient Na_2O was added to make the melt neutral and it was found that there was no foaming below the solidus temperature. Thus the observations on silicate melts seem to have a degree of generality.

Experiments were carried out in iron crucibles on melts containing lime, silica and iron oxide (the stoichiometry set by equilibrium with solid iron at temperature). Here it was found that there was erratic behavior in that in a small percentage of the runs that the froth would remain stable for an abnormally long time and then disappear almost at once. These runs were not considered as representative. Most of the runs indicated slight foam stability for large concentrations of 'FeO' in an acid silicate melt, and this behavior leads the authors to conclude that large quantities of 'FeO' do not result in foam stability.

The addition of both Fe_2O_3 and Cr_2O_3 to acid calcium silicate melts resulted in a definite maximum in a foam life vs. percent of metal oxide added to the original calcium silicate melt. This phenomenon is common in low temperature systems exhibiting foam stability and fits in well with the theoretical considerations on the role of *surface elasticity* in foam stabilization.

IMD Annual Business Meeting

11:45 am Sheraton-Atlantic Hotel Ballroom

O. T. Marzke, Chairman, Presiding

WEDNESDAY, FEBRUARY 17, PM

EMD Annual Stag Luncheon and Business Meeting

12:15 pm Sheraton-Atlantic Hotel Winter Garden

A. E. Lee, Jr., Chairman, Presiding

Presentation of EMD Award to *L. S. Renzoni*, *R. C. McQuire*, and *W. V. Barker*

Speaker: *Arthur Dean*, Sullivan and Cromwell
Subject: The Impact of the Anti-Trust Laws on American Business and on Our Ability to Compete With the Soviet Union

IMD-ISD Solidification II

(Arranged by ISD Physical Chemistry of Steelmaking Committee in Cooperation with the Institute of Metals Division)

2:00 pm Sheraton-Atlantic Hotel Ballroom

Chairmen:

R. E. Boni, Armco Steel Corp.,
T. B. King, Massachusetts Institute of Technology

Heterogeneous Nucleation in the Liquid-to-Solid Transformation in Alloys: *B. E. Sundquist* and *L. F. Mondolfo*, Illinois Institute of Technology.

The undercooling associated with the nucleation of the secondary phase by the primary phase has been studied in 60 binary alloy systems. The purpose of the work was to determine the general relationships between nucleating agent and nucleated metal that promote good or bad nucleation (low or high undercooling).

A special constructed hot-stage microscope apparatus was used in conjunction with the fine particle technique similar to the procedure used by Turnbull, Hollomon, and Cech in their investigations of maximum undercooling in metals and alloys. The eutectic and peritectic system investigated involved alloys primarily of Pb, Sn, Bi, Tl, Sb, Ag, Cu, and Au with some alloys containing Fe, Co, Ni, Te, Ge, Zn, Al, and Ca. Undercoolings varied from 0.0°C for the nucleation of Pb by Ni, Co, Cu, and Sn to $\geq$ 108°C for the nucleation of Cu by Ag.

The results of this investigation can be summarized as follows:
In a system of α and β it is usually found that α nucleates β at some low undercooling whereas β does not nucleate α except possibly at undercoolings approaching homogeneous nucleation. This behavior can be explained in terms of relative interfacial energies and shows that crystallographic disregistry between α and β is only a minor factor in heterogeneous nucleation. The metals investigated can be placed in a *nucleation series* in which a metal in the series nucleates the metals below it at low undercoolings and the metals above it at very high undercoolings if at all. The distribution of metals in the series seems to be controlled by the complexity of structure, the more complex metals such as Sb, Bi, and Ge being high, the simpler metals such as Pb and Tl, being low. An approximate relationship between the order in the series and the entropy of fusion has been found which permits estimating the nucleating power of a metal from its entropy of fusion.

In terms of the theory of heterogeneous nucleation based on relative interfacial energies the results indicate that, in the cases of low undercooling for the nucleation of β by α, $\sigma_{\alpha L} = \sigma_{\beta L} + \sigma_{\alpha\beta}$ with $\sigma_{\alpha L}$ significantly larger than $\sigma_{\beta L}$. In this formula $\sigma_{\alpha L}$ is the interfacial energy between solid α and the liquid (L) etc. Thus the criterion for nucleation of β by α at low undercooling is that nucleation occurs only when the solid-liquid interfacial energy of the nucleus is reduced by a coating of β forming on the α.

The Determination of the Eutectic Composition in Metal Alloy Systems by the Zone Melting Method: *A. S. Yue* and *J. B. Clark*, The Dow Metals Product Co.

During the zone melting of a two-phase alloy of a eutectic system the composition of the molten zone seeks the lowest melting composition in the alloy system i.e., the eutectic composition. Thus the zone melting technique can be adapted for the determination of the eutectic composition in complex metal systems. The application of this method is demonstrated in a simple eutectic system, Mg-Al, in which the eutectic composition is known and in a complex ternary system, Mg-Al-Zn, in which the literature is uncertain as to the composition of the ternary eutectic. The advantages and limitations of this new approach for the determination of the eutectic composition are discussed.

Some Engineering Aspects of Solidification of Metals: *M. C. Flemings* and *H. F. Taylor*, Massachusetts Institute of Technology.

A summary will be given of work conducted in the MIT Foundry Laboratory over the last eight years on solidification of light metals (aluminum and magnesium). Techniques will be discussed for improving the microstructure of cast metals, and thus the mechanical properties, while achieving a fine, equiaxed dendritic structure. These techniques consist of (1) reduction or elimination of brittle intergranular constituents by controlling composition and heat transfer, (2) reduction of microsporosity resulting from gas and/or solidification variables, and (3) careful control of all metal and mold variables. Control of interdendritic fluid flow is shown to be essential in elimination of microporosity due to shrinkage. Practical procedures based on the above findings are now being employed commercially to produce "premium quality castings" (castings with mechanical properties equivalent to those forgings of comparable composition).

Experiments will be described in which small ingots were produced with (1) equiaxed dendrites, (2) long columnar dendrites, and (3) complete absence of all dendrites (equiaxed or columnar); attendant improved properties resulting from controlled microstructures will be given.

Concluding remarks will be made regarding current work at MIT on the effect of solidification variables on structure and properties of steel castings and ingots, in which cast steel has been made with properties of 300,000 psi ultimate tensile strength and 30 pct reduction of area.

Interface Temperature of Two Media in Poor Thermal Contact: *G. Horvay* and *R. H. Edsall*, General Electric Co.

The following heat conduction problem is treated: Two semi-infinite media that are at different initial temperatures are brought into (poor) thermal contact. The transient one-dimensional heat conduction equation is solved exactly for the two regions. Expressions are obtained for the two interface temperatures at functions of time, the material properties of the two media, and the contact resistance. It is shown that the two temperatures gradually approach the well-known, instantaneously-assumed, common interface temperature of the case of zero contact resistance.

The effect of contact resistance upon heat transfer in aircraft structures has lately aroused considerable interest; but the slow-down of heat transfer occasioned by contact resistance is of equal concern in foundry operations. In this case the phenomenon is complicated by the occurrence of a change of phase in one of the media. It is found that the present analysis, with slight modification tions, may be used in fair approximation also for the class of problems involving a change of phase.

Viscous Shear as an Agent for Grain Refinement in Cast Metal: *F. A. Crossley*, *A. G. Metcalfe*, and *R. D. Fisher*, Armour Research Foundation.

The application of magnetic stirring to cast aluminum was found to produce significant grain refinement. Also, it was found that when cast aluminum was mechanically rotated, grain refinement occurred in that portion of the ingot which was solidifying during the period of acceleration of the molten metal to the rotational speed.

The grain-refining action of rotational motion may be explained on the basis of turbulence or acceleration of the liquid with respect to the solidification front during the freezing process. Acceleration of a liquid such that nonuniform rotational motion results is associated with a velocity or viscous shear gradient. That is, there is relative motion between adjacent layers of atoms in the liquid. Jost states that velocity (due to an external force) contributes directly to diffusion. The increase in diffusion rate due to rotational acceleration has two direct effects on nucleation during solidification: (1) the nucleation rate per unit volume of solidifying liquid is increased and (2) the volume of undercooled liquid (immediately in front of the solidification interface) in which nucleation can occur is increased as is also the degree of undercooling.

The first effect may be visualized as follows. Consider a critical-sized nucleation embryo. It grows by diffusion; and the frequency at which a single atom from the liquid phase joins it to promote it into a stable, growing nucleus is proportional to the number of atoms of liquid in contact with its surface. Under conditions of rotational acceleration the relative motion of liquid atoms with respect to the surface of the critical embryo results in a increase in the number of atoms to which it is exposed per unit time and therefore increases its chance of promotion to stable size.

The second effect may be readily seen by considering the effect of increased diffusion on compositional undercooling at the solidification interface, and perhaps upon the thermal gradient. The distance from the solidification interface at which the liquid composition rises (for a eutectic system) to the over-all alloy composition is decreased. Assuming that the thermal gradient remains constant, the result is that the volume of undercooled liquid is increased and the degree of undercooling is also increased. Assuming that the thermal gradient is lowered (a very likely possibility), then the volume of undercooled liquid and the degree of undercooling are further increased.

Fluid Flow Control During Crystal Growth From the Melt: *W. C. Johnston* and *W. A. Tiller*, Westinghouse Electric Corp.

Control of the hydrodynamic layer thickness, δ, at a solid liquid interface may be effected by applying a rotating magnetic field to the melt. Such a field creates a torque on the liquid causing it to follow the motion of the field. By controlling the plane of rotation and the field strength, H, the fluid flow can be controlled. This paper describes the variation of the hydrodynamic layer thickness, δ, with H when the field was rotating in the plane of the solid-liquid interface of a Pb-Sn alloy. It was studied by observing the variation of the effective partition coefficient, k, with freezing velocity. From this variation it was found that δ was given approximately by

$$\delta = Ae^{-mH^2}$$

where A and m are constants.

Instability of Solid-Liquid Interfaces: *G. F. Bolling* and *W. A. Tiller*, Westinghouse Electric Corp.

A simple zone melting technique for investigating the effect of ultrasonic irradiation upon ingot solidification is described. The effect of (1) ultrasonic power level, (2) freezing velocity, (3) constant or variable frequency, (4) direction of irradiation, and (5) transducer-coupling bar joint upon the grain refinement of type 316 stainless steel have been investigated. The results of this study support the postulate that the ultrasonic vibrations increase the nucleation probability in the layer of liquid adjacent to the freezing interface.

Application of Ultrasonics to Ingot Solidification: *D. Lane* and *W. A. Tiller*, Westinghouse Electric Corp.

A theoretical treatment of the solid-liquid interface shape during crystal growth leads to the determination of the degree of constitutional supercooling required for a planar interface to transform to a cellular interface. The transition depends upon the growth conditions, the thermal properties of the solid and liquid, the solid-liquid interfacial energy and the hydrodynamic layer thickness at the interface. It is predicted that single-phase alloy crystals (1 to 50 wt pct) may be grown with a stable planar interface if appropriate stirring is used.

WEDNESDAY, FEBRUARY 17, PM

EMD
International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt—Atmospheric and Elevated Pressure Leaching

2:00 pm Sheraton-Atlantic Hotel Colonial Room

Chairmen:
W. L. Lennemann, U.S. Atomic Energy Commission
F. L. Holderreed, The Anaconda Co.

Leaching and Electrowinning of Copper From Nchanga Oxide Concentrate: *F. H. Chapman*, Anglo American Corp. of South Africa, Ltd., and *E. W. Page*, Nchanga Consolidated Copper Mines Ltd., Southern Rhodesia.

Leaching of Chuquicamata Oxide Copper Ores: *J. A. McArthur* and *Clark Leaphart*, Chile Exploration Co., Chuquicamata, Chile.

Pressure Leaching of Nickeliferous Laterites With Sulfuric Acid: *E. T. Carlson* and *C. S. Simons*, Freeport Nickel Co.

Factors in Choice of Corrosion-Resisting Materials for Refining Equipment: *F. L. LaQue*, and *C. M. Schillmoller*, The International Nickel Co.

EMD Nuclear Fuels Reprocessing

(Arranged by EMD Nuclear Fuels Reprocessing Committee)

2.00 pm Sheraton-Atlantic Hotel Green Room

Chairmen:
J. A. Leary, Los Alamos Scientific Laboratory
W. D. Wilkinson, Argonne National Laboratory

Purification of Irradiated Nuclear Fuels by Crystallization from Liquid Metal Solvents: *S. Lawroski* and *H. M. Feder*, Argonne National Laboratory.

Use of Mercury in Reprocessing Nuclear Fuels: *O. C. Dean*, *A. F. Messing*, and *H. C. Forsberg*, Oak Ridge National Laboratory.

Experiments in Pyrometallurgical Processing of Thorium-Uranium Fuels: *G. E. Brand*, *E. W. Murbach*, *F. W. Dodge*, and *W. N. Hansen*, Atomics International.

The Aluminum Magnesium Pyrometallurgical Process for Spent Uranium Nuclear Reactor Fuels: *Robert J. Teitel*, Dow Chemical Co.

IMD Dislocations II

(Based on Submission of Research Abstracts)

2:00 pm Sheraton-Atlantic Hotel Red Room

Chairmen:
F. L. Vogel, Jr., Radio Corporation of America
J. J. Gilman, General Electric Co.

Direct Observation of Dislocations and Stacking Faults in Evaporated Silver Films: *V. A. Phillips*, General Electric Co.

High purity single crystal silver films were made by evaporation onto a substrate under controlled conditions. These were thin enough for examination by transmission electron microscopy. Small dislocation loops were observed apparently produced by the agglomeration and collapse of vacancy discs. Line dislocations, which may have been grown in or may have formed during *handling* of the film, were also seen and tended to dissociate into Shockley partial dislocations as a result of thermal stresses and the low

stacking fault energy. The partial dislocations were connected by stacking faults which showed many of the contrast effects predicted by Hirsch and Whelan, some of which have been previously observed in stainless steel. Occasional twins were formed.

Plastic deformation could be produced by locally heating the film in the electron beam and occurred by the movement of whole and partial dislocations. A number of interesting dislocation interactions were observed. A ciné film has been made on the screen of a Siemens Elmiskop I electron microscope at 40,000X. This shows the movement of dislocations, the formation of stacking faults and their interaction with other faults and dislocations.

Dislocations in Zinc Observed With Electron Microscope: *Norman Brown*, University of Pennsylvania, and *M. J. Whelan*, Cambridge University.

Specimens were specially prepared with the basal plane in the foil which came from single crystals grown from the melt. The observations were made with the Siemens Elmiskop I.

The most striking observation was the existence of dislocation loops as large as 1μ. There appear to be two types of loops: one type had an irregularly shaped periphery and showed a very marked change in contrast on the inside when the foil was tilted. Presumably this type of loop encloses a stacking fault. The other type was more rounded in shape and did not show contrast on the inside, but simultaneously at different points on its periphery showed invisibility, double, and triple images for certain angles of tilt. The kinetic theory of electron scattering does not appear sufficient to account for these effects.

A possible explanation for the loops is that there is a lattice collapse after the condensation of a disc of vacancies on the basal plane and then a shear to produce a stacking fault.

Twisted boundaries were observed after twisting the crystals about the [0001] axis. The expected network of dislocations was observed.

Basal and non-basal slip was observed. Some of the non-basal slip traces were wavy indicating cross-slip.

The annealing of the dislocation loops were observed qualitatively. Some loops disappear in a most irregular manner in that during annihilation some grow momentarily while others shrink. In general the loops behave like sessile rather than gissile dislocations. There are also interesting interactions between the loops and other dislocations.

Growth of Twins in Melt Grown Single Crystals of Tin as Observed by Transmission Electron Microscopy: *J. T. Fourie* and *Fred Weinberg*, Department of Mines and Technical Surveys, Canada

The initiation and growth of twins in melt grown single crystals have been examined by transmission electron microscopy. Controlled orientation single crystals of cross-section 1 x 20 mm were thinned down by electrolytic polishing techniques to a thickness suitable for electron transmission.

Foils with (001) and (110) faces have been examined as well as polycrystalline foils. Dislocation movement was observed in all instances. The formation of twins was observed primarily in the (001) foils and mostly in regions which were relatively free of dislocations. It was further found that twins were predominantly initiated either at the edge of the foil or at etch pits, while in some cases new twins originated at extisting twin boundaries. Selected area electron diffraction patterns of untwinned and twinned regions confirmed that the structures observed were in fact twins.

A Ciné film of the formation and growth of twins, their mutual interaction, and their interaction with dislocations will be shown. Rates of propagation of twins have been measured with the aid of this film, and are found to vary over a wide range in the region of 10^{-4} cm per sec.

Dislocation Theory of Strain Aging: *T. Mura*, *E. Lautenschlager* and *J. O. Brittain*, Northwestern University.

A theory and verifying experimental data are presented to explain the strain aging of iron and steel. The theory develops a relation between the number of carbon atoms migrating to a dislocation and the aging time which eventually leads to saturation. A term to account for the bulk diffusion which is due to the carbon concentration gradient developed in the vicinity of the dislocation is also included. The experimental results show the relation between the increase of the yield point after aging and the aging time. Both the theory and the experimental results differ from the empirical formula of Harper, which was made to modify the Cottrell-Bilby theory of strain aging.

Yield Point in Silicon-Iron: *J. C. Suits*, Harvard University.

The effect of stress and grain size upon pre-yield plastic deformation in polycrystalline 3 pct Si-Fe was studied by means of an etching technique sensitive to dislocation sites. The pre-yield plastic deformation was measured in terms of 1) percentage of yielded grains, 2) number of slip bands per grain, 3) dislocation spacing, 4) clusters of yielded grains, and 5) stress at which slip begins. These quantities give measurements of the lattice friction stress, the stress distribution of active sources, and the stress to propagate slip across grain boundaries. The effect of these quantities upon the macroscopic yield behavior is discussed.

Unloading Yield Point Effect in Pure F. C. C. Metals: *H. K. Birnbaum*, University of Chicago.

Yield point phenomena are observed in pure FCC metals during interrupted tensile deformation. These effects occur only if the stress on the specimen is reduced betwen consecutive tests. The behavior of a wide range of orientations of copper single crystals has been examined. It was observed that the magnitude of the yield effect is related to the work hardening of the crystal. The hardening which produces the yield phenomena was observed to be a transient effect. Combined tension-torsion tests were carried out to examine the role of dislocation pileups in these phenomena. The effect of removing a surface layer of the crystal by etching during the interrupted tensile deformation will be described.

The unloading yield effects can be shown to be due to a mechanism other than strain ageing. A mechanism for the effect will be described which is based on the rearrangement of piled up dislocations during the removal of the applied stress. The results of the present investigation and of other workers will be shown to be consistent with the proposed mechanism.

Effect of Initial Dislocation Density on the Plasticity of Germanium: *A. R. Chaudhuri* and *J. R. Patel*, Raytheon Co.

Dislocation-free germanium single crystals (as revealed by the etch pit technique) have been deformed in tension in the temperature range 500° to 700°C. The yield stress is raised by only a factor of about 2 on lowering the initial dislocation density from 10^8 to O per sq. cm. The initial dislocation density also appears to affect the brittle-ductile transition in germanium, the temperature of the transition being raised with decreasing dislocation density. Specimens having dislocation densities of less than about 10^2 per sq cm were found to behave in much the same manner as the dislocation-free samples. It was found that dislocations are created at comparatively small stresses on deforming crystals that were initially dislocation free, and the dislocation multiplication has been studied by etch pit techniques.

Yield Behavior in Germanium: *J. R. Patel* and *A. R. Chaudhuri*, Raytheon Co.

As found by other authors, germanium exhibits a large drop in stress at the yield point. The magnitude of the drop in stress at the yield point is found to be critically dependent on the dislocation content of the sample. With increasing dislocation density the yield point phenomenon becomes less pronounced. It was found that the yield point was preceded by a substantial pre-yield strain. As a result, about 10^5 dislocations per sq cm were introduced prior to the yield drop in initially dislocation-free samples. On reloading samples preciously stressed to within the pre-yield range the yield phenomenon could be suppressed. The effect of temperature and orientation on the yield point have been investigated. After stressing and prolonged strain-ageing the yield point is not appreciably recovered. The yield point phenomenon has been observed both in crystals grown in vacuum and in inert gas atmospheres. Dissolved gases or contamination due to heating germanium at elevated temperatures do not appear to have any marked influence on the behavior of the yield point.

IMD
Experimental Techniques and General Metallurgy

(Based on Submission of Research Abstracts)

2:00 pm Sheraton-Atlantic Hotel Blue Room

Chairmen:

Irving Cadoff, New York University
C. E. Birchenall, Princeton University

Continuous Resistance Apparatus for the Measurement of Fine Wire Uniformity: *A. I. Michaels*, *T. L. Weaver*, and *R. C. Nelson*, Sylvania Electric Products, Inc.

The paper describes the design and performance of an apparatus for making continuous and non-destructive resistance measurement throughout a spool of fine wire (<9.5 mil, diameter). Essentially the apparatus consists of a feed system and a mercury pool contact box both enclosed in a constant temperature box; a bridge network with a preamplifier and recorder to amplify and record the unbalanced current across the bridge, and a dc power supply, helipot, and milliammeter to supply and control the measuring current for the bridge. The bridge network utilizes a standard wheatstone bridge in which the moving wire becomes one arm, or alternately a specially designed bridge using a series of standard wires.

Results obtained on tungsten and molybdenum wires from 1 mil to 9.5 mil in diameter are reported. In all runs on both clean and graphite coated wires the measurements are shown to be highly reproducible. On cleaned wires there is a close linear relationship between resistance and wire weight (mg per 200 mm standard length). This correlation was not observed on black wire where large variations due to non-uniform coatings (tungsten oxide and graphite) mask the diameter variations, but still held on uniformly coated wires. The technique is thus applicable to measurement and control of diameter variations.

Preliminary work indicating a correlation between resistivity and tensile strength is described. These results reveal the additional high potential of this apparatus as a non-destructive technique for the measurement of various physical properties of fine wire.

Determination of Oxygen in Steel by Isotope Dilution: *M. L. Pearce* and *C. R. Masson*, National Research Council of Canada.

The method of stable isotope dilution, first applied to the determination of oxygen in metals by Grosse and his co-workers, has been refined and extended to the determination of the smaller concentrations present in iron and steel. The method consists essentially of fusing a metal sample in contact with carbon and allowing the melt to attain equilibrium in an atmosphere containing a measured quantity of carbon monoxide enriched in the isotope O^{18}. The isotope ratio $O^{16}:O^{18}$ in the gas mixture is determined before and after equilibration by means of a mass spectrometer. It has been found that the ratio of ion currents at *m:e* 30 and 28 in the final gas mixture is not an accurate measure of the $O^{18}:O^{16}$ ratio due to the interference of nitrogen which is liberated by the steel and which contributes significantly at *m:e* 28. Although it is possible to estimate the component of the ion current at *m:e* 28 due to CO alone, a more accurate procedure is to convert part of the carbon monoxide to carbon dioxide and to utilize the ion currents at *m:e* 44 and 48 or 46 and 48. Conversion to carbon dioxide is accomplished by allowing the gas mixture to circulate continuously a hot platinum filament and through a trap cooled in liquid air, thus displacing the equilibrium $2CO \rightleftarrows CO_2 + C$.

The reproducibility of the results is comparable with that obtained using the more conventional vacuum-fusion technique, being of the order of ±0.002 pct O for presumably homogeneous samples, and is independent of the gross oxygen content over the range 0.006 pct to 0.03 pct. The most significant feature of the results is that they are consistently higher than those obtained using the vacuum-fusion method of analysis. In an effort to explain this discrepancy it has been shown that the film deposition on the furnace wall by a molten metal sample retains some carbon monoxide even after several hours of degassing under high vacuum. When CO^{18} is brought into contact with such a film, exchange occurs and the resulting dilution has been used to estimate the quantity of CO^{16} adsorbed on the film. Steels containing manganese may be analysed by this technique provided the enriched gas is allowed to equilibrate with the furnace system before the metal sample is introduced.

Some Aspects of Vacuum-Fusion Analysis: *C. R. Masson*, National Research Council of Canada.

An investigation has been made of some features which might be expected to influence the accuracy of determination of oxygen and nitrogen in steels, particularly of low gas content, when analysed by the vacuum-fusion method. With the apparatus described, quantities of gas of the order of .01 ml at STP could be measured with an accuracy of ±1 pct. Using a water-cooled furnace tube, experiments have been done with the following three designs of crucible assembly: (1) An assembly similar to that described by Sloman in which the crucible, insulated by graphite powder, is supported on a graphite pedestal. (2) An assembly closely resembling that designated by Guldner and Beach in which the crucible, insulated by graphite powder held in a quartz container, is suspended in the furnace by platinum wires, and (3) An assembly similar to that used in isotope dilution experiments, in which the crucible is suspended directly in the furnace by wires of platinum-rhodium alloy, no graphite powder or other cold graphite parts being present. Gas analyses were performed both chemically and by mass spectrometry. With both the Sloman and Guldner-Beach assemblies, the rate of evolution of gas from the crucible increased markedly after it had been allowed to stand overnight at room temperature, but gradually decreased to an extrapolation of its former value on renewed de-gassing at the working tempreature. This effect was not observed with the isotope-dilution assembly. Except with the Guldner-Beach design, no nitrogen was ever detected in the blank gas from a crucible alone, although nitrogen was always present in the blank after a steel sample had been analysed. Although quantitative recovery of both nitrogen and carbon monoxide could be obtained when known amounts of these gases were admitted to the furnace, this is not regarded as conclusive evidence that the recovery of gas from a steel sample is complete. The presence of water-vapor in the evolved gases was sought by attaching the mass spectrometer directly to the outlet of the furnace pumps. Although water-vapor was often the major constituent of the blank, it is not an important constituent of the gas evolved from a steel sample.

Use of Neutron Irradiation for Detecting Boron Segregation in a High-Temperature Alloy: *J. S. Rudolph* and *J. T. Brown*, Westinghouse Electric Corp.

Boron has been reported to have a variety of effects in high-temperature alloys. Most of the theories explaining these effects deal with the segregation of boron to some particular location in these alloys. Because of this boron effect, knowledge of its distribution within the alloys is important. Since conventional methods of microconstituent analysis do not possess sufficient sensitivity and resolution to enable the detection and location of boron within these alloys, autoradiographic procedures were investigated.

In this investigation, the boron-10 isotope was added to an iron-base, precipitation-hardened alloy. Four heats were cast containing 0.0002, 0.006, 0.022, and 0.083 pct by weight of boron-10 as determined by chemical analysis. Metallographic specimens were prepared from wrought bar stock in the as-forged, solution-treated, and solution-treated and aged conditions (12 specimens). These specimens were coated with alpha-sensitive autoradiographic stripping film and irradiated with slow-moving neutrons from a thermal reactor. Photographic images of the high boron locations in the samples were obtained from activation of the stripping film by alpha particles, making use of the following reaction:

$$_5B^{10} + _0n^1 \rightarrow [_5B^{11}] \rightarrow {}_3Li^7 + {}_2\alpha^4 + 2.8 \text{ meV}.$$

The resulting autoradiographs allow an interpretation of the effect of increasing amounts of boron on the gain size and precipitation reactions. A description of the autoradiographic procedure and a discussion of the metallurgical results are presented in this paper.

High Temperature Metallographic Technique for the Study of Tungsten and Molybdenum Recrystallization: *R. C. Nelson* and *J. H. Milier*, Sylvania Electric Products, Inc.

WEDNESDAY, FEBRUARY 17, PM

A description of the high temperature metallographic technique employed for the photographic (both sequential and motion picture studies) observation of the recrystallization of tungsten wire. Includes a description of the attachment designed to be used in conjunction with a B. & L. research metalloscope, as well as a description of the metallographic technique for the preparation of wire specimens. The technique permits the wire samples which have been polished to the center to be heated in an inert atmosphere by their own resistance so that they remain in focus for photographic observation.

High temperature photomicrographs are presented as pictorial illustrations of the mode of recrystallization of tungsten and molybdenum wires as influenced by composition and process history. Included are illustrations from wires of various manufacturers. Potential applications are reviewed.

Effect of the Transition Elements on the Recrystallization of Iron: *E. P. Abrahamson, II*, and *B. S. Blakeney, Jr.*, Watertown Arsenal.

The effect of the transition elements in binary solid solution additions, up to 1 at. pct, upon the recrystallization temperature of iron has been investigated. All of these elements immediately raise the temperature of recrystallization, many having the majority of their greatest effect in less than 0.10 at. pct. A correlation is noted between the rate of change of recrystallization temperature with atomic percent solution and the ground state electron configuration of the added element. An explanation is proposed to account for this correleation.

Thermodynamic Properties of Iron-Aluminum Alloys: *J. M. Eldridge* and *K. L. Komarek*, New York University.

Thermodynamic properties of aluminum in solid iron-aluminum alloys have been determined by equilibrating thin specimens of iron and iron-aluminum alloys with aluminum vapor in a static system. A reaction between $Al_{(l)}$ and $NaCl_{(l)}$, to form a volatile compound $AlCl_{(g)}$ was utilized to effect a much more rapid transfer of Al from its reservoir to the specimens than by direct evaporation of Al alone.

The specimens were distributed along the length of the inside of a vertical, high-purity Al_2O_3 tube which was closed on the upper end and loosely fitted at the open bottom end inside a high purity Al_2O_3 crucible. A loose-fitting cylindrical aluminum plug was sandwiched between the bottom of the tube and the crucible. Two smaller crucibles were positioned above the plug, one containing aluminum and the other sodium chloride. The assembled tube with its contents was heated in a vacuum system, setting up a temperature gradient along the length of the tube such that the Al and NaCl were at the temperature minimum. As the tube was heated, the Al plug melted to effectively seal off the tube, and the run was continued until equilibrium was attained. In equilibrium, the specimens contain aluminum of the same partial pressure as that given by the equilibrium for the Al + NaCl ⇄ AlCl + Na reaction.

The chemical composition of the resulting iron-aluminum alloy was determined, and this together with the knowledge of the temperature gradient, permitted calculations to be made of the partial molal thermodynamic functions of aluminum. The activity of Al was found to show a very strong negative deviation from Raoult's Law up to 50 at. pct. This behavior is thermodynamically in agreement with the known equilibrium phase diagram of the iron-aluminum system and with the very limited data published by other investigators.

Isothermal Section of the Nb-Zr-Ti-O System at 1500°C: *W. C. Wyder* and *Michael Hoch*, University of Cincinnati.

The isothermal section of the Cb-Zr-Ti-O system at 1500°C was investigated, using powder X-ray diffraction and micro-metallographic methods. The samples were prepared by mixing the metal powders and their oxides and heating them to 1500°C under high vacuum until equilibrium was obtained. The system showed no quaternary compounds. The Cb-Zr-Ti face forms a continuous series of body-centered beta solid solutions.

CbO is quite insoluble in TiO_2 and in ZrO_2. However, a mixture of 70 pct TiO_2 and 30 pct CbO added to ZrO_2 stabilizes cubic ZrO_2 just as do mixtures of TiO_2 and TiO. In the CbO-ZrO_2-TiO_2 plane a two-phase region of cubic ZrO_2 and $TiZrO_4$ exists. From the various equilibria the free energy of formation of CbO at 1500°C was calculated to be between −70.3 and −80.4 kcal per mol., which is more negative than the value quoted in the literature (−62.0).

CbO_2 and ZrO_2 were found to be immiscible but CbO_2 and TiO_2 formed a complete series of solid solutions.

Addition of oxygen to the Cb-Zr-Ti body-centered beta solid solution face gave the following four-phase regions up to the CbO_2-ZrO_2-TiO_2 plane (where *t* = tetragonal, *c* = cubic, *α* = hexagonal, and *ss* = solid solution):

$$\beta + t\text{-}ZrO_2 + \alpha Ti + TiO$$

$$\beta + t\text{-}ZrO_2 + TiO + c\text{-}ZrO_2$$

$$\beta + TiO + c\text{-}ZrO_2 + Ti_2O_3$$

$$\beta + t\text{-}ZrO_2 + c\text{-}ZrO_2 + CbO$$

$$\beta + c\text{-}ZrO_2 + CbO + Ti_2O_3$$

$$c\text{-}ZrO_2 + CbO + Ti_2O_3 + Ti_3O_5$$

$$c\text{-}ZrO_2 + CbO + Ti_3O_5 + TiO_2$$

$$c\text{-}ZrO_2 + CbO + t\text{-}ZrO_2 + (CbO_2.TiO_2)\,ss$$

$$c\text{-}ZrO_2 + t\text{-}ZrO_2 + (CbO_2.TiO_2)\,ss + TiZrO_4$$

No liquid phases were detected at this temperature and oxygen concentration.

WEDNESDAY, FEBRUARY 17, PM

Further Study of Ti_2Ni-Type Phases Containing Titanium, Zirconium or Hafnium: *M. V. Nevitt, J. W. Downey,* and *R. A. Morris,* Argonne National Laboratory.

A previous paper reported the occurrence of a group of Ti_2Ni-type phases (structure-type $E9_3$) containing Zr or Hf in combinations with Rh, Pd, Ir or Pt and cited evidence to show that some of these phases occur only when O is present. Results can now be reported for a broader experimental survey of the occurrence of Ti_2Ni-type phases in binary alloys of Ti, Zr or Hf with a first, second or third long period transition metal and in corresponding ternary alloys in which O is the third component. The existence of eight previously unreported isomorphs is cited and for the ternary systems Zr-Fe-O, Zr-Rh-O, Zr-Ir-O, and Zr-Pt-O the approximate phase boundaries are given. Lattice parameters are reported for all of the new phases. The periodic table relationships involved in the occurrence of the phase are treated in terms of a qualitative correlation with valency electron concentration and atomic size.

Lattice Expansion of Thallium Above and Below Room Temperature: *J. I. Medoff,* and *Irving Cadoff,* New York University.

The Lattice Expansion of high-purity (99.995 pct) thallium was carried out in a 19-cm high temperature powder camera from room temperature up to 182°C and from room temperatures down to −97°C on the cold stage of a geiger counter wide-angle diffractometer. Wire specimens approximately 0.015 to 0.020 in. diam were used.

The lattice constants at room temperature were found to be $a = 3.4560$ A, $c = 5.5248$ A, and the c/a axial ratio was 1.598 ± 0.001 A.

The variation of the lattice parameters with temperature was found to be positive, the c-axis expansion being slightly larger than that in the a-axis direction, resulting in a gradually increasing c/a ratio. The low-temperature lattice values verified the general trend of the above room temperature expansion.

The linear thermal expansion coefficients calculated from the lattice expansion measurements show the anisotropy of the c-axis expansion to be considerably smaller than previously reported. The coefficients calculated for the 20 to 100°C range were found to be $\alpha_c = 37.8 \times 10^{-6}$, $\alpha_a = 26.1 \times 10^{-6}$.

MBD-IMD-EMD
Basic Science Symposium on Surface Phenomena for Mineral, Ceramic, and Metallurgical Systems

(Arranged by Basic Science Committee of Minerals Beneficiation Division)

2:00 pm Statler-Hilton Hotel Sky Top

Chairmen:

P. L. de Bruyn, Massachusetts Institute of Technology

Samuel Korman, Republic Aviation Corp.

Crystal Growth in Solids: *D. Turnbull,* General Electric Co.

The phenomenology and theory for the motion of crystal interfaces in solids will be reviewed. The main emphasis will be on crystal reorientation processes (grain growth) but some consideration will be given to other solid state transformations including the devitrification of glass.

Crystallization processes are very familiar phenomena and they have been investigated intensively for many decades. Notwithstanding this most crystallization reactions are still neither well specified nor understood. Crystallization is not a homogeneous process but rather one that occurs entirely at interfacial regions which, at any given instant, constitute only a minute fraction of the system. Thus our lack of understanding of crystallization reflects, in large part, our lack of understanding of the structure of interfaces and their interactions with impurity atoms.

Recently the theory for the structure of the crystal-dilute fluid interface and for its motion was greatly advanced by Frank and his associates. However, excepting in certain limits, the theory for the solid-solid case is in a much more primitive state.

The formal theory for the motion of interfaces in crystal reorientation processes will be summarized. Experimentally, it has been very difficult to disassociate boundary structure from impurity (whether in solution or precipitated) effects. Some important recent developments bearing on this problem and their consequences will be discussed.

Quantitative information concerning the rate of crystal growth in other solid state transformations is very limited even though the experimental techniques seem to be not too formidable. In this case also we have little understanding of the boundary structure and boundary-impurity interactions.

Surface Chemistry and the Kinetics of Sintering Processes: *W. D. Kingery,* Massachusetts Institute of Technology.

Sintering is the process whereby a powdered compact is transformed into a stronger, denser product after being subjected to heat treatment. The major energy change which takes place during the process is the decrease in surface energy corresponding to the lower surface area of the resulting product. The available driving force for the process depends on the specific surface energy and also on the initial particle size. These factors, together with a factor measuring the resistance to material transfer, determine the kinetics of the sintering process.

When the process takes place in a single phase, the material transfer mechanism may be volume diffusion, vaporization-condensation, viscous flow, or surface diffusion. Examples of each of these cases are known. The driving force is the surface energy of the solid material. The main factors which affect it are composition and atmosphere. Metals are particularly subject to changes in surface energy with small changes in composition; these changes are shown to affect the rate of sintering and the final product characteristics.

In multi-phase systems the surface energy relationships that control the sintering process are more complex. The case of most practical interest is when the liquid phase present completely penetrates between each of the solid grains; that is, when the dihedral angle is zero. Under these conditions,

$$\gamma_{SV} > \gamma_{LV} > \gamma_{SS} > 2\gamma_{SL} \qquad [1]$$

Two processes commonly take place simultaneously during sintering. One is grain growth of the solid particles; the second is increased density of the overall system. The driving force for grain growth is the decrease in solid-liquid interface energy when the grain size increases. The major driving force for the densification process is the decrease in surface area between the liquid and vapor phases and the overall decrease in the surface energy of the system.

As seen in Eq. [1], complete wetting requires that the solid-liquid interface energy be low. Consequently, the surface tension of the liquid contributes a larger part of the overall energy change than the change in grain size. For maximum densification rates, the surface energy of the liquid should be as large as possible, compatible with complete wetting of the solids.

If the liquid phase does not completely penetrate between solid particles, densification can only occur by the same general processes that also take place in solid state sintering; that is, with a solid bridge present between particles, shrinkage (and consequently densification) requires that material within the solid phase be transferred away from the line between particle centers. An additional mechanism for change in grain shape is solution and precipitation from the solid; this is equivalent to vaporization-condensation processes in the solid state, and as for vaporization-condensation, this cannot lead to densification. As a result, the surface energy relationship that is particularly important for obtaining high densities with the addition of a liquid phase is the relative values of the solid surface energy, the liquid surface tension, and the solid-liquid interface energy. Unless these are such that complete wetting results and the liquid penetrates between particles, the densification rate will not be increased (and in fact may be decreased) by the addition of a liquid phase.

Several systems in which the surface energy relationships affect the resulting sintering processes will be discussed.

Geometric Equilibria and Nonmetallic Microstructures: *L. H. Van Vlack,* University of Michigan.

This presentation is concerned with the role of geometric equilibria in developing microstructures in nonmetallic materials. The nonmetallic phases include those that are found as nonmetallic inclusions in steels and those that are found in ceramic materials. The presentation utilizes the principles which were advanced by C. S. Smith when he accounted for the microstructures of many metals.

A direct analogy may be made between microstructures in metals and microstructures in nonmetals because each has grain and phase boundaries. The atoms along the boundaries require more energy than do the atoms within the phase. Therefore the number of atoms along the boundaries is going to be spontaneously reduced so that the total energy will be decreased. (1) A growth in grain size reduces the phase and grain boundary areas. (2) The boundary areas are reduced through the anhedralization of euhedral grains. (3) A minimum energy can be achieved by a vectorial balance at the grain edges and corners where three and four boundaries meet. Examples of SiO_2-FeO compositions show each of these microstructural changes in nonmetallic materials.

Several nonmetallic examples are given to show that the energy of a phase boundary is directly related to the compatibility of the structures of the two phases. Examples include: (1) Sulfide and silicate nonmetallic inclusions in iron and steel in which the composition can be varied isothermally; (2) Sulfide-silicate couples in which temperature and composition (and therefore structure) may be varied together; and (3) glass-silicate couples in which the temperature and the oxidation level may be varied with little change in composition or structure.

The rate of microstructural equilibration is generally slower in nonmetallic materials than in metal. This is presumably a result of higher activation energy requirements for atomic diffusion in the more complicated nonmetallic structures. Nonmetallic phases with simpler structures normally will adjust to the interfacial energy more rapidly. Examples range from simple binary liquids to more highly coordinated silicates. There is evidence to suggest that the major part of microstructural equilibration occurs by bulk diffusion through the phase rather than along the grain boundary interfaces.

Nonmetallic microstructures of industrial interest will include: (1) refractory microstructures, (2) reaction between refractories and liquid metals, and (3) nonmetallic inclusions in steel.

The good high temperature service strength of silica brick may be explained on the basis of extensive solid-to-solid contact of the cristobalite even though considerable liquid may be present. This solid-to-solid contact is normally lacking in magnesia brick since the dihedral angle of a siliceous liquid between the periclase grains is zero unless some other oxide such as Fe_2O_3 is present. Thus the impure hot face zone and the metal (actually oxide) bonded portions of the brick are stronger than the bulk of the brick.

On the basis of recent microstructural studies it is necessary to revise our interpretation of the role of interfacial energies upon the penetration on molten iron into sand molds. Previously it had been concluded that molten iron wets silica sand under oxidizing conditions and does not wet silica under reducing conditions. The most recent work has shown that iron will not wet silica under either condition. Rather a separate oxide phase is formed under oxidizing conditions. This oxide phase wets and dissolves the silica as it penetrates into the sand molds. Larger pores result so that molten metal may penetrate the sand under hydrostatic pressure.

Geometric equilibria are of interest with nonmetallic inclusions because the presence of a nonmetallic liquid along the grain boundaries may produce a hot-short metal. Hot-shortness and cracking are developed in a steel under the pressures of hot working even though the liquid film does not completely separate the solid grains. In practice, the liquid film is not a simple composition but includes a melt of oxide, sulfide and silicate. Consequently we are not yet ready to make generalizations about the microstructural distribution of inclusions in steel.

The chief conclusions indicate that considerable information can be obtained by studying the microstructures of the nonmetallic materials. The basic principles that are involved for nonmetallic microstructures are the same as those for metallic microstructures.

Graphite Formation and Surface Tension in Cast Iron: *J. Keverian*, General Electric Co.

Data will be presented on the surface tension and contact angle of various carbon-saturated iron alloys as measured on a graphite plaque. The sessile drop technique was employed and calculations were based on tables prepared by Bashforth and Adams. Supplementary data of other investigators will be presented.

Values of the surface tension and contact angle of these alloys as measured in vacuo and carbon monoxide gas will be presented. This data will be analyzed with the aid of Young's equation and the Gibbs' adsorption equation in an effort to determine the effect of various elements upon the graphite-melt interfacial energy.

Sulfur is found to be a surface active element in iron-carbon alloys, reducing its surface tension and concentrating at the melt-vapor interface. There is evidence to indicate that sulfur is also adsorbed at the graphite-melt interface. One of the effects of cerium and presumably other graphite-spherodizing elements, such as magnesium, is to act as a scavenger of this surface active element. In this manner, the addition of graphite-spherodizing agents results in an increase of interfacial energies in this system.

The microstructures of these alloys and several theories of graphite formation in cast iron will be presented. These theories will be analyzed in the light of the above data as well as several nucleation and growth theories.

All-Institute Annual Banquet and Reception

7:00 pm Statler Hilton Hotel Grand Ballroom and Terrace Ballroom

Howard C. Pyle, President, AIME, Presiding

THURSDAY, FEBRUARY 18, AM

EMD Light Metals

(Arranged by EMD Light Metals Committee)

9:00 am Sheraton-Atlantic Hotel Ballroom

Chairmen:

C. L. Brooks, Reynolds Metals Co.
W. S. Peterson, Olin Mathieson Chemical Corp.

Production of Beryllium Metal of Nuclear Purity: *C. W. Schwenzfeier, Jr.*, Brush Beryllium Co.

Olin-Revere Alumina from Surinam Bauxite: *J. C. Russell*, Singmaster and Breyer, *L. L. Feickert* and *W. S. McConnell*, Ormet Corp.

ISD Acid Converter and Basic Oxygen Steelmaking I

(Arranged by ISD Acid Converter and Basic Oxygen Steel Committee)

9:00 am Sheraton-Atlantic Hotel Winter Garden

Chairmen:

A. W. Thornton, United States Steel Corp.
H. B. Emerick, Jones & Laughlin Steel Corp.

New Developments in Acid Bessemer Steelmaking: *A. B. Wilder*, National Tube Division, United States Steel Corp.

Oxygen Steelmaking Practice at Kaiser Steel: *Barney Dagan*, Kaiser Steel Corp.

End Point Temperature Control of Basic Oxygen Furnace: *W. J. Slatosky*, Jones & Laughlin Steel Corp.

Present Status of Steel Specifications Met by Oxygen Steel: *R. N. Dobson*, Dominion Foundries and Steel, Ltd.

THURSDAY, FEBRUARY 18, AM

EMD Aqueous Electrolytic Processes and Related Operations

(Arranged by EMD Electrolytic Processes Committee)

9:00 am Sheraton-Atlantic Hotel Colonial Room

Chairmen:

T. I. Moore, American Zinc Co. of Illinois
D. E. Warns, St. Joseph Lead Co.

Germanium in the Electrolytic Zinc Cell: *W. F. Zelezny*, Phillips Petroleum Co., and *J. H. Foreman*, Anaconda Aluminum Co.

Selection and Application of Stainless Steel in the Electrolytic Refining of Zinc: *C. M. Schillmoller*, The International Nickel Co.

Mechanical Casting of Slab Zinc: *R. K. Carpenter* and *P. M. Dampf*, American Zinc Co.

This paper describes the melting and casting operation of the American Zinc Co. of Illinois' electrolytic zinc plant located at Monsanto, Illinois. Since 1955 casting has been done mechanically on a casting wheel. The wheel receives metal from an Ajax induction feed furnace equipped with three pouring spouts. The Ajax casting wheel feed furnace is connected by launder with a reverberatory cathode melting furnace.

Three slabs of zinc are poured while three others are lifted from the wheel moulds simultaneously by means of vacuum and dropped on a conveyor. The wheel is operated at a casting rate of ten tons of slabs per hour.

Iron from Pickle Liquors: *C. L. Mantell* and *L. G. Grenni*, Newark College of Engineering.

Two Decades of Electrolytic Manganese Production: *C. L. Mantell*, Consulting Engineer.

IMD Titanium Research Abstracts

(Arranged by IMD Titanium Committee; Based on Submission of Research Abstracts)

9:00 am Sheraton-Atlantic Hotel Green Room

Chairmen:

P. A. Farrer, New York University
D. W. Levinson, Armour Research Foundation

Effect of Hydrogen on the Mechanical Behavior of Aged Alpha-Beta Titanium Alloys: *R. A. Nadler* and *D. L. Day*, Titanium Metals Corp. of America.

In view of the increased use of heat treatments for titanium alloys in recent years, an investigation was begun to determine if hydrogen in the concentrations normally found in commercially-produced Ti-155A (Ti-5Al-1.3Fe-1.3Cr-1.2Mo), Ti-6Al-4V, and Ti-4Al-3Mo-1V could result in embrittlement when these alloys were solution treated, aged, and placed in service.

Specimens of Ti-155A and Ti-6Al-4V bar, and Ti-6Al-4V and Ti-4Al-3Mo-1V sheet were degassed or hydrogenated to 15-334 ppm hydrogen, aged to tensile strengths in the order of 150,000 to 200,000 psi, and subjected to notched stress-rupture tests and tensile tests at two strain rates. All tests were performed at room temperature.

No embrittlement was observed during slow strain-rate tensile testing of the three alloys, and any reductions in tensile ductility were related to the high strengths found at high hydrogen levels. In all cases the observed values of tensile ductility were representative for the alloy and strength level.

Some reduction in stress-rupture life was seen in all alloys near the 200 ppm hydrogen level, but specimens with over 300 ppm hydrogen still passed the 100-hr rupture tests at high notched tensile stresses. Inconsistencies in the data and a relatively low initial level of ductility prevented accurate determination of the hydrogen tolerance for aged Ti-4Al-3Mo-1V, but there was no evidence that this alloy is any more susceptible than Ti-155A or Ti-6Al-4V. Metallographic evidence of a hydride phase was absent for each alloy even at the highest hydrogen contents.

It is concluded that no premature service failures of aged Ti-4Al-3Mo-1V, Ti-6Al-4V, or Ti-155A should occur as a result of hydrogen, since early failures of stress-rupture specimens occurred at very high stresses or when the hydrogen content was substantially above that found in commercially-produced titanium alloys.

Effects of Interstitial Solute Atoms on the Fatigue Limit Behavior of Titanium: *H. A. Lipsitt*, Wright Air Development Center.

A fatigue study in completely reversed axial tension-compression has been performed on high purity titanium and on three high purity alloys of titanium. The alloys each contain a single

interstitial element; approximately 0.75 at. pct of C, Ni, and O, respectively. Hardness, tensile and strain aging data are also presented.

The results corroborate a previously published theory which proposed, for the case of carbon and nitrogen in iron, that strain aging under alternating stress was responsible for the fatigue limit behavior of certain alloys. The present data indicates that the interstitial solute atoms O, C, and N, respectively, provide increasing strain aging propensity under alternating stress.

Transformation Characteristics of a Beta-Phase Titanium Alloy: *R. A. Rawe, J. M. Dupouy,* and *M. B. Bever,* Massachusetts Institute of Technology.

The transformation behavior of a titanium alloy containing 11 pct Cr, 13 pct V and 4 pct Al has been investigated by hardness measurements, X-ray diffraction and metallography.

The solution treated alloy consisted entirely of beta phase. Aging at temperatures between 700° and 1150°F increased the hardness; the rates of hardening suggested that beta decomposed by different modes upon aging above 1050°F and below 900°F and by a combination of these modes between these temperatures. X-ray diffraction analysis indicated that in the upper-temperature range the reactions $\beta \rightarrow \beta_r + \alpha \rightarrow \beta_n + \alpha + TiCr_2$ occurred, while in the low-temperature range, the transition phase omega appeared and the reactions were $\beta \rightarrow \beta_r + \omega \rightarrow \beta_n + \alpha$. Two modes of decomposition were also suggested by the microstructures.

A TTT diagram is proposed on the basis of these results. The hardening is attributed to the precipitation of omega and alpha and to solid solution hardening of the remaining beta.

An increase in solution time did not change the hardness of the solution treated specimens but decreased the rate of subsequent hardening. Cold working of solution treated specimens accelerated hardening and raised the hardness levels attained.

Transformation Kinetics of Three Titanium-Base Alloys: *L. E. Tanner,* Manufacturing Laboratories, Inc.

A study was made of the transformation kinetics of three commercial titanium sheet alloys using two standard heat treatments. The $\alpha - \beta$ alloys, Ti-2.5Al-16V and Ti-4Al-3Mo-1V, were: (a) β solution annealed followed by step-quenching to $\alpha + \beta$ reaction temperatures, and (b) $\alpha + \beta$ solution annealed, water quenched and then reheated to the reaction temperatures. The "all-β" alloy, Ti-3Al-11Cr-8V (or B120-VCA) was subjected to comparable heat treatment cycles using a β solution anneal in both cases. Several experimental techniques were used in complementary fashion. Metallographic examination and hardness testing provided a major portion of the data; critical or confirming information was obtained by electrical resistivity, dynamic elastic modulus, and X-ray diffraction methods. TTT diagrams were constructed for the above alloys and the important features of the transformations are described.

Structures and Properties of Titanium-Rich Titanium-Nickel Alloys: *J. W. Barton, G. R. Purdy, R. Taggart,* and *J. G. Parr,* University of Alberta.

The constitution and mechanical properties of heat-treated alloys containing up to 10 pct Ni in titanium have been investigated. Both quenched and tempered, and isothermally heat-treated alloys were investigated in order to relate properties to structure, and to determine C-curves.

The production of martensitic alpha, or Widmanstatten alpha, or retained beta can be explained on the basis of the relationship between the knee of the C-curve and the *Ms* temperatures (which were determined by cooling curve techniques).

Although the production of the omega phase (in both as-quenched as well as in tempered alloys) leads to hard and brittle structures, the precipitation of Ti_2Ni during tempering is associated with a decrease in hardness and tensile strength.

Titanium Alloys Based on Metal with Oxygen Content Below the Critical Range for Effect on Transformation Mechanism: *R. S. Dean,* Chicago Development Corp.

The usual parameters for studying transformation in titanium, such as thermal arrests, electrical resistance and expansion, provide information about the rearrangement of the titanium atoms in the lattice but do not record, except indirectly, the rearrangement of oxygen in the lattice.

The anodic electrode potential, on the other hand, reveals changes in oxygen activity as the metal passes through the transformation range. This results in easily measured cups in the electrode potential cooling curve. These cups are still readily apparent in titanium containing as little as .03 pct O but disappear discontinuously as the oxygen is lowered below about .02 pct.

Although the transformation from beta-alpha in the cooling process is not revealed by electrode potential in titanium with less than about .02 pct O, the beta-alpha transformation nevertheless takes place as revealed by X-ray examination of the cooled specimen. Low oxygen in titanium, therefore, does not prevent the transformation from beta-alpha but when oxygen is below a certain limit of about .02 pct it does not change position in the lattice and accordingly activity is not recorded by electrode potential.

Based on the transformation characteristics of the low oxygen-titanium a number of alloys have been developed. These alloys are of two kinds, beta stabilized with amounts of beta stabilizing element beyond that at which martensitic transformation takes place in ordinary titanium alloys and alpha alloys with high aluminum which in ordinary titanium alloys result in second phase formation at high temperatures.

The practical preparation of these alloys requires high purity materials not heretofore commercially available.

Titanium-Aluminum Alloy Behavior: *W. B. Aufderhaar* and *C. D. Dickinson,* Mallory Sharon Metals Corp.

Early difficulties encountered in development of thermally stable Ti-Al alloys with more than 5 pct Al raised questions as to the validity of the early titanium-aluminum phase diagram, which indicated a solid solubility of 24.5 pct Al in alpha titanium. However, as technology in the refining, melting and alloying of titanium developed, the original limits on the amount of aluminum which could be used in titanium alloys were found to be only temporary limits.

The choronological development of titanium alloys with useful tensile and creep strength at higher and higher temperatures parallels and follows the technical developments which have permitted the use of higher aluminum contents. As evidence, consider he Ti-4Al-4Mn, Ti-6Al-4V, Ti-7Al-3Mo and finally alloys containing 8 pct Al, Ti-8Al-2Cb-1Ta, Ti-8Al-1V-1Mo and Ti-8Al-8Zr-1(Cb + Ta).

The object of the present work was to determine the extent of improvement in strength at elevated temperatures with aluminum contents greater than 8 pct and to determine and attempt to resolve the problems of thermal instability and embrittlement in these alloys.

Alloys investigated contained from 8 to 25 pct Al with minor ternary and quaternary additions of other elements to determine the effect of these additions on elevated temperature strength and thermal stability. A careful study of those elements which alter the aluminum embrittling reaction was conducted. The effect of heat treatment and impurities on the properties of these alloys is discussed in light of the embrittling reaction.

The results of the survey program strongly indicate that the problems of embrittlement of Ti-Al alloys containing more than 8 pct Al will only be resolved after the nature and mechanics of the embrittlement are understood. We do not feel that we have this understanding at this time, but we have determined some of the behavior which will help to an explanation and eventual solution of the Ti-Al embrittlement problem.

IMD Deformation and Fracture I

(Based on Submission of Research Abstracts)

9:00 am Sheraton-Atlantic Hotel Red Room

Chairmen:

Maxwell Gensamer, Columbia University

J. L. Zambrow, Sylvania-Corning Nuclear Corp.

Plastic Deformation of Aluminum Single Crystals as a Function of Temperature: *S. Howe,* and *C. Elbaum,* Brown University.

The temperature dependence of the stress-strain curves of aluminum single crystals with <100>, <110> and <111> axial orientations was studied. Single crystals were extended at room temperature, 200°, 400° and 600°C. Examination of the curves reveals that as the temperature is raised, both the shape of the curves and the levels of flow stress become similar until at 600°C, the curves for the different orientations are almost identical and show little work hardening. On the other hand, the surfaces of the crystals extended at 800°C are quite different, the <110> crystals showing predominantly slip, the <100> crystals double slip, and the <111> crystals multiple slip.

The above results are interpreted in terms of current theories of work hardening and its temperature dependence. In particular it is shown that above a certain temperature the stress-strain relationship becomes independent of the kind and number of operating slip systems. It is, therefore, concluded that above this temperature plastic deformation is controlled by a mechanism which is independent of the kind of obstacles to slip encountered in aluminum single crystals at lower temperatures.

Strength of Aluminum Base Zinc Alloys: *John Dash* and *M. E. Fine,* Northwestern University.

The critical resolved shear stresses (CRSS) of Al-base Zn alloys up to 5.3 at pct Zn were measured from room temperature to 77°K for both the zone-hardened and solid solution conditions. Single crystals were prepared by the strain anneal method. The zone-hardened state was produced by water quenching from 460°C and aging 24 hr at room temperature; the reverted (solid solution) state was produced by heating a hardened alloy to 200°C for 5 min. The structures were checked by X-ray diffraction.

CRSS of the zone-hardened alloys increases approximately with $(C_a - C_s)^{1/2}$ where C_a is the atomic concentration of Zn in the alloy and C_s is the atomic fraction of Zn in the matrix solid solution present with the zones. Such behavior is predicted for the chemical strengthening due to cutting of zones by dislocations. CRSS of the 5.3 at pct Zn alloy increases rather sharply from 6.8 to 8.4 kg per sq mm on cooling from 196° to 77°K.

For the supersaturated solid solution the CRSS at 298°K increases from 0.34 to 1.3 kg per sq mm as C_a is increased from 1.6 to 5.3 pct Zn. CRSS for this condition also increases sharply on cooling below 196°K being 0.7 kg per sq mm for the former and 1.7 kg per sq mm for the latter alloy. The measurements are being extended to 4.2°K.

Sintered Bicrystals of Silver: *J. J. Hauser* and *B. Chalmers,* Harvard University.

Silver bicrystals of special geometries were prepared by the sintering together of single crystals. The boundaries so formed were found to affect the plastic deformation of the crystals in the same way as *grown* boundaries do. The effects of the boundaries are discussed in terms of the plastic compatibility of the adjacent

crystals. Bicrystal specimens in which one crystal is surrounded by the other crystal have been prepared by the sintering technique. Their deformation behavior is reported and discussed in terms of compatibility, and of the implications with relation to the behavior of polycrystalline samples.

A Study of the $\{10\bar{1}1\}$ and $\{10\bar{1}3\}$ Twinning Modes in Magnesium: *R. E. Reed-Hill*, U. S. Coast Guard Academy.

The polarized light technique for magnesium, recently reported by Couling and Pearsall, makes possible the determination of lattice reorientation in small crystalline regions such as deformation twins. This method has therefore been used to re-examine two twinning forms which appear in magnesium crystals strained in tension parallel to the basal plane. Because these twins are very small and appear in extensively deformed regions they do not lend themselves to X-ray analysis. Lacking the polarized light method, the two twinning plane indices (K_1) were determined originally by two surface measurements of the composition planes, both falling in a major zone (axis $<11\bar{2}0>$) making angles of 29° and 55.75° respectively with the parent crystal basal plane. Neither coincided with a low indice lattice plane, but the 29° habit fell close enough to $(10\bar{1}3)$, 32°, to justify the assumption that here $(10\bar{1}3)$ was the twinning plane. However, because the 55.75° habit deviated by 6° from $(10\bar{1}1)$, 61.9°, the experimental data per se were not consistent with simple $(10\bar{1}1)$ twinning and, therefore, this twin was designated with habit plane indices $(30\bar{3}4)$ at 54.5°, representing the lowest set of indices corresponding to measured angles.

Re-examination of deformed crystals with the polarizing microscope shows that the deformations previously identified as primary twins are in reality second order twins; retwinning occurring on the $(10\bar{1}2)$ plane of first order $(10\bar{1}3)$ and $(10\bar{1}1)$ twins. Areas in the first order orientation were found only at the extreme ends of some twinned deformations. Lattice reorientations within both the first and second order twinned volumes, as well as the composition planes of the small first order areas, are consistent with primary twinning on $(10\bar{1}3)$ and $(10\bar{1}1)$. The 29° and 55.75° habits of the larger central regions of the deformations are those of second twins. There is, thus, a difference between the habit of first and second order twins which follows from the manner in which the deformations form and grow under increasing stress. Measurements of basal slip line deflections resulting from twinning shears strongly indicate that $(10\bar{1}1)$ and $(10\bar{1}3)$ are reciprocal twins; K_1 (first undistorted plane) of one form equal to K_2 (second undistorted plane) of the other. The twinning shear of these reciprocal twins is small (0.136) and of the same order as the twinning shear in $(10\bar{1}2)$ twins.

Microstrain in Polycrystalline Metals and the Grain Size Effect: *Norman Brown*, and *K. F. Lukens, Jr.*, University of Pennsylvania.

A theory was developed for describing the dependence of microplastic strain on stress and grain size of polycrystalline metals. The microplastic strain is given by

$$\gamma = C\rho D^2(\Gamma - \Gamma_0^\rho)^2/G\Gamma_0^\rho$$

where $C \approx 1/2$, ρ is density of sources, Γ, applied stress, Γ_0^ρ, stress to move first dislocation, G, modulus, and D, grain size.

The theory was checked by measuring the stress strain curve in the micro-region using a capacitance type extensometer. The metal investigated was ingot iron with grain sizes from 44 to 140 μ. The agreement between the theoretical equation and the experimental data was excellent not only in the case of the iron, but for data on copper and zinc from the investigation of others. The density of sources in ingot and copper was 2.5 and 6.9 sources per cu cm respectively. The range of the microstrain region has been calculated in terms of the amount of microstrain that occurs at the macroscopic yield point.

As a useful sidelight, it turns out that annealing ingot iron at 650°C after a microstrain completely removes the work hardening so that the specimen returns to its initial state. Consequently, the same specimen may be used repeatedly for tests in the microstrain region.

Effect of Microstructure on the Mechanical Properties of Ti-V, Ti-Al-V, and Ti-O-V, Alloys: *R. W. Douglass, F. C. Holden, H. R. Ogden*, and *R. I. Jaffee*, Battelle Memorial Institute.

The reaction kinetics and mechanical properties of high-purity titanium-vanadium alloys containing from 2 to 40 wt pct v were investigated. Low temperature aging and cooling rate studies were used to study reaction kinetics. Room-temperature tensile properties and impact behavior over a range of temperatures were determined for various microstructural conditions.

Maximum strength and minimum ductility for β-quenched titanium-vanadium alloys occurred at about the minimum composition for retaining β on quenching; at higher vanadium contents a composition range of mechanically unstable β was found, characterized by low yield-to-ultimate tensile strength ratios; at still higher vanadium contents mechanically stable β of high strength and ductility was obtained.

The highest strengths were produced in alloys aged after quenching from the β field; maximum ductilities were developed by annealing high on the α-β field followed by a low temperature equilibration anneal. A comparison of equiaxed and acicular α-β structures showed little change in strength but a significant reduction in ductility for the acicular-type structure at low alloy compositions.

Low temperature aging treatments to study reaction kinetics resulted in (a) slight hardening at low alloy contents due to decomposition of martensite and ω to equilibrium α and β, (b) peak hardening from ω formation on quenching and rapid overaging in a Ti-12V alloy, and (c) sluggish, although significant, aging response at higher alloy contents. The study of reaction kinetics from the effect of cooling rate from the β filed on hardness showed maximum hardenability on water quenching in the Ti-12V alloy; alloys with slightly higher vanadium contents were fully hardened at slower cooling rates.

Additions of 2.5 and 5.0 pct al and 0.2 pct O_2 to the binary alloys increased strengths both from solid solution effects and changes in the reaction kinetics. The influence of aluminum additions on reaction kinetics was demonstrated in cooling rate and aging studies of β-quenched alloys. Decreased hardness and strength and increased aging time to attain maximum hardness as compared with ω-hardened binary alloys were observed. The increased sluggishness in the β-to-ω transformation resulted in a significant reduction in the yield-to-ultimate tensile strength ratio in the composition range 12 to 20 pct V.

Oxygen additions produced an effect opposite to that of aluminum additions in accelerating the rate of ω formation as indicated by aging and cooling rate studies. Tensile data, however, showed that the oxygen addition to the Ti-12V alloy acted to inhibit ω formation and reduce the tensile strength with an attendant increase in ductility.

Strain Rate and Temperature Dependence of the Ductile to Brittle Transition in Molybdenum Subjected to Torsional Loading: *Daniel Weinstein, G. M. Sinclair*, and *C. A. Wert*, University of Illinois.

Brittle failure in annealed arc-cast molybdenum in torsion was studied as a function of strain rate and temperature. Strain rates ranged from a maximum of 12.5 per sec to a minimum of 0.005 per sec. The temperature dependence of the yield point for these different strain rates was used to calculate a heat of activation for the yield point. The heat of activation was not a constant but was approximately a linear function of the stress at yield. The value extrapolated to zero stress is 36,000 cal per mole. This is close to the reported value of 33,400 cal per mole for carbon diffusing in molybdenum. It is proposed that the rate effect in yielding is determined in part by diffusion of carbon (or other interstitial atom) in the metal.

Ordering and Creep Properties in Ni-Cr-Al Alloys: *C. M. Hammond*, Allegheny Ludlum Steel Corp, and *R. A. Flinn* and *Lars Thomassen*, University of Michigan.

The purpose of this investigation was to study the structural transformations present in the Ni_3Al-Ni_2Cr system and to correlate the transformations with changes in elevated temperature properties. According to the literature, two transformations were possible: 1) long range ordering of the γ solid solution, rich in Ni and Cr, and 2) precipitation hardening by an ordered γ' phase based upon Ni_3Al.

No long range ordering was found in the γ solid solution by elevated temperature X-ray diffraction. Conventional X-ray diffraction patterns of quenched specimens contained superlattice reflections, but these reflections resulted from precipitation of the ordered phase, γ', during quenching.

Therefore, in these alloys, the important transformation affecting creep properties is the precipitation of the ordered phase γ'. This precipitation of γ particles markedly increases the elevated temperature properties at 750°C (1382°F). The yield strength is increased by a factor of 5 to 6 with decreased elongation. The creep strength (i.e., the stress necessary to produce a creep rate of 0.001 pct per hr at 750°C (1382°F)) is increased 5 to 6 fold by γ' precipitation. Changes in the size of the γ' dispersion did not significantly affect the creep strength at 750°C (1382°F).

Investigation of Atmosphere Effect on Stress-Rupture Properties of Two Aluminum Alloys: *K. B. Lloyd, P. Shahinian*, and *M. R. Achter*, U. S. Naval Research Laboratory.

Stress-rupture tests were conducted, at 400°, 500°, and 600°C, in vacuum and in air, on two alloys, 1100 aluminum and Alcoa experimental M-257 alloy. The experimental alloy was a sintered and extruded powder metallurgy product, containing 7.8 pct al_2O_3 in a matrix of commercial purity metal approximating the 1100 aluminum composition. Data showing the effect of atmosphere environment in reducing the ductility of 1100 aluminum alloy, and creep curves, minimum creep rate and rupture life data for the two alloys are presented. Rupture lives in the vacuum tests were consistently longer than in the air tests at all three temperatures with the dispersion hardened alloy; the effect increasing with higher temperature and lower stresses. A reversal of properties was found in the 1100 aluminum alloy tests at 400° and 500°C—the vacuum test lives were shorter at the high stress levels and longer at the low stress levels, at 600°C the vacuum test lives were all longer than the air test lives.

These reversals in aluminum are in direct contrast to those found in previous work on the atmospheric effect on stress-rupture properties of nickel and nickel base alloys, where the air test lives were longer at the lower stress levels. Competing processes of air strengthening by internal oxidation and air weakening by reduction of surface energy by gas adsorption were proposed to explain the nickel reversals. The application of these processes in this study is discussed to explain how the oxidation characteristics of aluminum alloys could account for their different response to environment.

THURSDAY, FEBRUARY 18, AM

EMD
Second Extractive Metallurgy Division Lecture

11:00 am Sheraton-Atlantic Hotel Ballroom

Speaker: *C. R. Kuzell*, Phelps Dodge Corp.

Subject: The Development of Modern Copper Smelting

THURSDAY, FEBRUARY 18, PM

ISD
Acid Converter and Basic Oxygen Steel Committee Luncheon

12:15 pm Sheraton-Atlantic Hotel Blue Room

A. B. Wilder, Chairman, Presiding

EMD New Developments in Extractive Metallurgy of the Refractory Metals

(Arranged by EMD High-Temperature Metals Committee)

2:00 pm Sheraton-Atlantic Hotel Ballroom

Chairmen:
L. W. Coffer, Battelle Memorial Institute
R. G. Jones, Wah Chang Corp.

Formation of Tantalum and Columbium Fluorides from Carbided Ores by Reaction with Anhydrous Hydrofluoric Acid: *R. A. Gustison, E. Peters*, and *S. D. Pinkoski*, Union Carbide Metals Co.

Carbon-Oxygen-Vanadium Equilibrium: *J. H. Downing*, Union Carbide Metals Co.

Columbium—From Ore to Metal: *K. C. Li*, Wah Chang Corp.

Preparation of Scandium Metal: *H. M. Dess, J. H. Downing*, and *K. H. Heffels*, Union Carbide Metals Co.

Fused Salt Electrorefining of Tungsten: *F. Cattoir, R. Cumings*, and *D. H. Baker, Jr.* U. S. Bureau of Mines.

ISD Acid Converter and Basic Oxygen Steelmaking II

(Arranged by ISD Acid Converter and Basic Oxygen Steel Committee)

2:00 pm Sheraton-Atlantic Hotel Winter Garden

Chairmen:
Gerhard Derge, Carnegie Institute of Technology
C. C. Benton, Algoma Steel Corp.

New Steelmaking Facilities at Acme Steel Company: *C. J. Petry*, Acme Steel Co.

Summary of Latest Developments in L-D Steelmaking Outside of North America: Osterreichisch Alpin Montan Gesellschaft, Donawitz, Austria.

Pneumatic Processes at Converting High-Phosphorus Iron: *Pierre Coheur*, Centre National de Recherches Metallurgiques, Liege, Belgium.

Metallurgical Characteristics of Kaldo Oxygen Steelmaking Process: *Bo Kalling*, Stora Kopparbergs Bergslags AB, Domnarvet, Sweden.

EMD
International Symposium on the Extractive Metallurgy of Copper, Nickel, and Cobalt—Refining

2:00 pm Sheraton-Atlantic Hotel Colonial Room

Chairmen:
J. L. Wyatt, Booz, Allen, and Hamilton
J. H. Schloen, Canadian Copper Refiners, Ltd.

Industry Report on Copper Tankhouse Practice: *J. H. Schloen* and *S. S. Forbes*, Canadian Copper Refiners, Ltd., and *S. B. Tuwiner*, Osborn & Tuwiner.

Electrolytic Tank House Operations and Cell Room Practice at Chuquicamata, Chile, S. A.: *J. A. McArthur* and *B. J. Ledeboer*, Chile Exploration Co., Chuquicamata, Chile.

Production of Refined Nickel Sulphate of ASARCO's Perth Amboy Plant: *D. A. Busch, J. R. Stone, G. Chiszar*, American Smelting and Refining Co.

Industry Report on Cobalt Refining: *L. S. Renzoni*, International Nickel Co. of Canada, Ltd., *M. Bouchat*, Union Miniere du Haut-Katanga, Brussels, Belgium, and *V. N. Mackiw*, Sherritt Gordon Mines, Ltd.

IMD Powder Metallurgy—Dispersion Hardening and Strengthening

(Arranged by IMD Powder Metallurgy Committee; Based on Submission of Research Abstracts)

2:00 pm Sheraton-Atlantic Hotel Green Room

Chairmen:
Robert Steinitz, Sylvania Electric Products, Inc.
H. H. Hausner, Consultant

Survey of Dispersion Strengthening in Metals and Alloys: *R. F. Bunshah*, and *C. G. Goetzel*, New York University.

The status of dispersion strengthening in metals and alloys was recently surveyed. The published and unpublished literature as well as current investigations in US and Europe were reviewed. Theories on dispersion strengthening were examined and the structural and other variables which govern their strength and stability are outlined.

The results of the survey indicate that dispersion strengthened alloys exhibit outstanding properties at elevated temperatures when the right structural conditions are present i.e the interparticle spacing in the range 0.01 – 0.1 μ, as well as, high hardness of the dispersed phase, low interfacial energy between matrix and dispersed phase (in most cases). Other contributing factors are stored energy, coherency strains, and matrix strengthening by solid solution. It must be emphasized that no general prescription for high strength in these alloys can be written as the predominant strengthening mechanism or variable depends on the temperature and duration of test or service. The stability of these alloys at service temperatures, which is dependent on the rate of agglomeration of the dispersed phase, is enhanced by high thermodynamic free energy of formation of dispersed phase, low or negligible solubility and low diffusivity of the components of the dispersed phase in the matrix.

The results are discussed in terms of the structural and other variables and the theories compared with the results. A large number of techniques can be used to produce dispersions in metals and alloys. The report contains a summary of these techniques.

Much further work both of a fundamental nature to delineate the role of various variables and the oriented toward alloy development remains to be done. Dispersion strengthening particularly in refractory metals appears most promising and should be a very fruitful area of investigation.

Dispersion Hardening in the Copper-Alumina System: *K. M. Zwilsky*, New England Materials Laboratory, and *N. J. Grant*, Massachusetts Institute of Technology.

Dispersion hardening was investigated in the copper-alumina system utilizing several different copper powders (1, 5 and -74 μ) for the matrix and three alumina powders (0.018, 0.033 and 0.3 μ) as the dispersed phase. Alloys containing from 2.5 to 10 vol. pct alumina were prepared by powder metallurgy techniques and were evaluated by means of room temperature tensile and elevated temperature creep-rupture tests.

Improvement in the strength properties for the powder alloys was found to depend on the particle size of the starting materials used, the highest values being recorded for mixtures of the finest copper and alumina particles available. In terms of the stress for a 100 hr rupture life, the best alloys were stronger than pure copper by a factor of 10 at 450°C and a factor of at least 12 at 550°C. Room temperature yield values were increased by a factor of 8 and tensile strength was increased from 2 to 3 times that of pure copper. The elongation values remained at as reasonable level.

Resistivity measurements showed that the strongest alloys had from 65 to 70 pct the conductivity of pure copper.

A drop-off in strength recorded for some of the alloys was related to the crystallographic transformation of alumina, from the γ to the α structure which resulted in the agglomeration of particles throughout the structure of the alloy.

Dispersion Hardening of Copper: *Oliver Preston*, Stanford Research Institute, and *N. J. Grant*, Massachusetts Institute of Technology.

A series of copper-silica and copper-alumina alloys containing from 0.1 to 12 vol. pct of the oxide in finely dispersed form were prepared by the hot extrusion of internally osidized, −20 mesh alloy powders. Tensile tests at room temperature and creep-rupture tests from 450° to 850°C were conducted on these alloys in the as-extruded condition. Usually high creep-rupture strength and thermal stability were observed in a copper-3.5 vol. pct alumina alloy. This material showed approximately 60 pct of the electrical conductivity of pure copper: Its yield strength decreased only from 65,000 psi to 59,000 psi on annealing for 1 hr at 1000°C. Measurable recrystallization did not occur after 1 hr at 1050°C.

Oxide particle sizes were determined from X-ray line broadening measurements on extracted residues, from which interparticle spacings were calculated. Attempts to relate strength to particle size and spacing by means of some common dispersion hardening theories were not successful.

A dispersion hardening model is suggested, based on the effect of the dispersed phase on the retention of strain energy from the extrusion step. On the basis of the proposed model, a correlation is shown between strength and oxide dispersion and some inferences of the model are discussed.

Effects of Stored Energy and Recrystallization on the Creep Rupture Properties of Internally Oxidized Copper-Alumina and Copper-Silica Alloys: *Masao Adachi* and *N. J. Grant*, Massachusetts Institute of Technology.

Dilute solid solution alloys of copper-silicon (0.07 and 0.25 pct) and copper-aluminum (0.09 and 0.23 pct), which were internally oxidized in powder form and then compacted, sintered and extruded, gave oxide dispersion hardened alloys of Cu-SiO_2 (0.6 and 2.1 vol. pct) and Cu-Al_2O_3 (0.4 and 1.1 vol. pct). These low oxide content alloys were noted to undergo some degree of recrystallization after exposure at temperatures near to melting point of copper.

Accordingly, various amounts of recrystallization were achieved at temperatures of 1050°C for varying periods of time. The degree of recrystallization was checked primarily by hardness and metallography.

Creep-rupture tests were conducted at 450°C for time periods up to about 500 hr and were compared to the results previously obtained on as-extruded material. A definite decrease in strength takes place with increasing degrees of recrystallization, accompanied by an increase in ductility.

After partial or complete recrystallization, a few test bars were cold worked. Creep rupture tests, again at 450°C, indicated that partial to complete recovery of the strength values was possible through such cold work.

A hypothesis regarding the role of stored energy in these oxide dispersion hardened structures is presented.

Dispersion Hardening: *W. H. Meiklejohn* and *R. E. Skoda*, General Electric Co.

The effect of the size and spacing of a dispersed second phase on the yield strength of a metal was determined in the iron mercury system. This system was chosen because the size and spacing of the iron particles in the mercury could be independently varied. The iron was electrodeposited into the liquid mercury and because of the very small solubility of the iron in the mercury 50A particles of iron pop out in the mercury. These can be grown by heat treatment to 1000A, and the spacing between particles can be varied by adding mercury. Tests were performed on extruded specimens at 77°K.

A modified Orowan dependence of the yield strength on the particle spacing was assumed and was shown to hold for a given particle diameter. However, it is obvious from the experiments that the yield strength depends on the particle diameter. The equation resulting from these experiments for the increase in yield strength is given by

$$\sigma_T - \sigma_0 = \frac{C\,(d/\Lambda)}{1 - d/\Lambda}$$

where σ_T and σ_0 are the yield strength with and without particles, d is the diameter of the particles, Λ is the distance between centers of the particles, and C is a constant. It is obvious that the increase in yield strength depends only on the ratio d/Λ. Since the ratio d/Λ is directly proportional to the cube root of the volume fraction of the dispersed phase, it is easily shown that the increase in yield strength depends only on the volume fraction of dispersed phase.

Influence of Processing Variables on the Properties of Nickel-Aluminum Oxide Alloys: *L. J. Bonis* and *N. J. Grant*, Massachusetts Institute of Technology.

In the preparation of metal-metal oxide dispersion hardened alloys by mechanical mixing techniques, a number of steps are subject to difficult control, leading to poor properties and making reproduction of alloys and alloy properties difficult.

THURSDAY, FEBRUARY 18, PM

Using 5μ nickel powder and 0.018μ Al_2O_3, alloys were prepared by mechanically mixing the powders in desired proportions, followed by compaction, sintering and extrusion to produce 0.3 in. diameter bar stock with about a 20 to 1 extrusion ratio.

The processing variables which were studied were: (a) Cooling of the powder during mixing; (b) electrostatic discharging to minimize clustering; (c) changes in amount of oxide for this combination of powder diameters; (d) changes in mixing time; (e) sintering versus no sintering.

Proper control of these and other factors led to the attainment of a 9 vol. pct Al_2O_3 alloy with reproducible properties. Such an alloy shows superior creep rupture properties to Inconel X, Nimonic 100, Waspalloy, Inco 700 and other commercial age hardenable alloys at temperatures greater than about 1800°F. Good room temperature properties were also obtained.

Effect of Dispersion on the Ductile-Brittle Transition of Silver Chloride: *T. L. Johnston*, *R. J. Stokes*, and *C. H. Li*, Minneapolis-Honeywell Regulator Co.

Under given impact bending load conditions, notched polycrystalline silver chloride has been found to have a ductile-brittle transition at approximately 55°C. Microscopic examination has shown that below this temperature cracks propagated both intergranularly and by transcrystalline cleavage. Above this temperature, specimens absorbed impact without fracture.

The addition of alumina in the form of irregularly shaped and spherical particles respectively, had a profound influence upon the form and temperature of the ductile-brittle transition. The effects stemmed primarily from the ability of disperse particles to induce fibrous cracking and thereby increase the energy absorbed during crack propagation.

Making use of the optical and electron microscope, correlations have been obtained between the macro-and microscopic appearance of the fracture surfaces of specimens and the kind and amount of alumina they contained. Such correlations will be discussed.

IMD Deformation and Fracture II

(Based on Submission of Research Abstracts)

2:00 pm Sheraton-Atlantic Hotel Red Room

Chairmen:

J. R. Low, Jr., General Electric Co.

L. S. Castleman, Sylvania Electric Products, Inc.

On the Fracture of Metals Under Impulsive Loading Conditions: *J. L. O'Brien*, Harvard University, and *R. S. Davis*, Arthur D. Little, Inc.

The fracture stress for four high-purity polycrystalline face center cubic metals (aluminum, nickel, silver and copper) has been determined experimentally, under impulsive loading conditions. The ratio of the theoretical fracture stress, (as determined by an extrapolation of the equation of state data recently published by the Los Alamos group, into the region of hydrostatic tension) to the observed fracture strain was found to be 9:1 for the four metals. For one of the metals, aluminum, it was found that the fracture stress is independent of structure and composition.

The fracture stresses obtained in this investigation are at least an order of magnitude greater than those observed for the highest strength alloys of the metals in question, under quasi-static conditions.

New observations on the scabbing phenomenon, that have resulted from this investigation, will be discussed.

Tensile Deformation of Sodium Chloride: *R. J. Stokes*, *T. L. Johnston*, and *C. H. Li*, Minneapolis-Honeywell Regulator Co.

Recently it has been emphasized that a study of the innate mechanical properties of ionic solids is possible only when special precautions are taken to eliminate surface microcracks and crystalline deposits. It is the purpose of this paper to describe some of the features of the deformation and fracture of sodium chloride when the surface has been carefully prepared.

Single crystals of sodium chloride may be elongated in tension by approximately 40 pct before fracture. It is interesting to note that throughout plastic deformation slip in any given region of the gage length prefers to be confined to a single slip plane. Fracture occurs by cleavage from an internal source the nature of which is not fully understood.

The observation that slip takes place over a single plane has permitted us to perform critical experiments with regard to the origin of cracks at surface crystalline deposits. Evidence will be presented which indicates that these cracks are formed by the pile up of edge dislocations at the interface between the base crystal and the surface deposit.

In contrast to the ductility of single crystals, polycrystalline sodium chloride is extremely brittle when tested in tension even though the same precautions are taken in surface preparation. Fracture occurs chiefly by cleavage although it *always* has its origin at a grain boundary which has ruptured intergranularly. Reasons for this marked change in mechanical behavior will be discussed.

THURSDAY, FEBRUARY 18, PM

Influence of Slip Distribution on the Mechanical Properties of Magnesium Oxides Single Crystals: *R. J. Stokes, T. L. Johnston,* and *C. H. Li,* Minneapolis-Honeywell Regulator Co.

The ductility of magnesium oxide can be correlated with the density and distribution of slip. Polished crystals tested under tension behave in one of three characteristic ways: (i) Slip is confined to a single slip band which expands to cover the whole gage length. Such crystals elongate by~5 pct. (ii) Slip occurs on a few orthogonal intersecting slip bands. These crystals are extremely brittle and plastic deformation cannot be measured, i.e. pct. (iii) Slip occurs on many orthogonal intersecting slip bands. These crystals elongate~3 pct.

These observations can be interpreted in terms of the nucleation and propagation of cracks formed as a consequence of plastic flow. Cracks nucleate at the intersection of two orthogonal slip bands in polished crystals and take the form of slits lying along the line of intersection; their propagation is stopped by an adjacent slip band and their width is thus defined by the slip band spacing. For the case (i) where there is no intersecting slip, cracks are not nucleated within the gauge length and the crystals are fairly ductile. In case (ii) a crack forms before sufficient stabilizing slip is introduced, consequently it accelerates to a velocity high enough to overcome any impedance which might be offered by other slip bands and the crystal fractures. In case (iii) there are sufficient slip bands present to impede the crack propagation and prevent it attaining catastrophic dimensions.

For a given polished crystal there is no means of telling beforehand whether it will be brittle, (ii), or ductile, (i) and (iii). However, introducing slip sources into the crystal surface artificially, e.g. by sprinkling it with silicon carbide powder, forces a fine-distribution of intersecting slip throughout the gauge length. Crystals for which slip has been homogenized in this way are *consistently* ductile in tension.

Direct Observation of Crack Formation as a Consequence of Plastic Flow: *K. H. Olsen, R. J. Stokes, T. L. Johnston,* and *C. H. Li,* Minneapolis-Honeywell Regulator Co.

A 16 mm motion picture will be shown which illustrates the three types of mechanical behavior distinguished in the previous paper. The films were taken during the deformation of polished magnesium oxide crystals under tension. The slip band distribution was revealed by the stress birefringence produced with polarized illumination. The most interesting sequence occurs in connection with type (iii), where a crack, once formed, can become stabilized by the adjacent slip bands. Two examples of the formation of stable cracks may be seen. The stress field associated with dislocation pile up at intersecting slip bands can be seen to relax in both cases as the cracks develop. Eventually one of the cracks breaks through its stabilizing slip band and the crystal fractures in two, observations agreeing with the fracture mechanism described by Stokes et al. on the basis of indirect observations on magnesium oxide single crystals deformed by bending.

Grain Boundary Sliding in Ionic Materials: *M. A. Adams, A. Iannucci,* and *G. T. Murray,* Materials Research Corp.

Bi-crystal shearing experiments are being used in an attempt to clarify the controversy concerning the contribution of grain-boundary sliding to the creep process in ceramic type materials. Boundary sliding has been found in NaCl bi-crystals subjected to a pure boundary shear stress of 140 g per sq mm at 600°C ($0.8T_M$), and this sliding occurred, as with metals tested in pure shear, without plastic deformation of the grains. The amount of sliding is dependent on boundary orientation when stress and temperature are fixed. MgO bi-crystals have also been tested in pure shear but no sliding was found at temperatures up to 1040°C., with boundary shear stresses as high as 1650 g per sq mm; one specimen tested at 1230°C and 600 g per sq mm showed a small movement (4×10^{-5} cm) but then fractured along the boundary.

Movement has also been observed in compressive tests at 1500°C on MgO bi-crystals in which the boundaries were inclined at 45° to the applied load. In these tests separation along the boundary also occurred before the tests could be stopped. At present compressive tests are being made on MgO over a range of stresses and temperatures in an attempt to obtain boundary movement without separation.

Relation of the Stored Energy of Cold Work to Work Softening: *A. L. Tichener,* University of New Zealand, and *M. B. Bever,* Massachusetts Institute of Technology.

When a polycrystalline gold-silver alloy was cold worked at −195°C to a true strain of 0.6 and brought to room temperature, its stored energy decreased from 90 to 51 cal per g-atom. Additional working at room temperature to a total strain of approximately 1.0 reduced the stored energy further to about 30 cal per g-atom. This release of stored energy induced by cold work is analogous to the phenomenon of work softening, which was first observed with single crystals of aluminum and copper. Hardness measurements on the gold-silver alloy also showed this phenomenon.

Possible mechanisms operating to reduce the stored energy during secondary deformation at room temperature were considered. They must involve imperfections that are thermally stable at room temperature but are rendered unstable by cold work; in addition they must account for the amount of energy evolved and the observed decrease in hardness. Mechanisms involving vacancies, stacking faults and, less definitely, twinning faults are dismissed because they fail to meet one or several of these criteria. Annihilation of dislocations is considered to be the most probable mechanism.

An Investigation of the Effects of Explosive Loading on a Gold-Silver Alloy: *A. S. Appleton* and *M. B. Bever,* Massachusetts Institute of Technology, and *G. E. Dieter,* E. I. du Pont de Nemours and Co.

The stored energy, hardness, and microstructure of a gold-silver alloy deformed by explosive loading have been investigated as a function of shock pressure. After loading at a pressure of 120 kilobars, the stored energy was of the order of 3 cal per g-atom. At 150 kilobars, the stored energy increased to 25 cal per g-atom; it remained at approximately that value up to 500 kilobars. Over the whole range of shock pressures investigated, the hardness increased nearly continuously, but the rate of increase appeared to be largest in the range of 120 to 150 kilobars. In this same pressure range, deformation twins were first noted. At higher pressures twins were present in all grains. These changes are compared with those produced in the same alloy by conventional deformation processes.

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Jan. 25-29, Stress Measurement Symposium, sponsored by *Strain Gage Readings*, Arizona State University, Tempe, Ariz.

Jan. 29, Philadelphia Section, AIME, Annual Meeting featuring election of officers and "Ladies Night."

Feb. 12, Southwestern section, NOHC, Spring Meeting, Lennox Hotel, St. Louis.

Feb. 14-18, AIME Annual Meeting, Sheraton-Atlantic Hotel (formerly McAlpin) and Hotel Statler, New York.

Feb. 16-19, Symposium on Hydrometallurgy, *Wet Processing of Minerals and Industrial Products*, The Australasian Institute of Mining & Metallurgy, Adelaide, Australia.

Mar. 9-10, Symposium on Processing of Materials for Re-entry Structures, The Mid-West Society of Aircraft Materials and Process Engineers, Dayton, Ohio.

Mar. 15-21, Third International Conference on Nondestructive Testing, Tokyo, Mar. 15-18; Osaka, Mar. 21.

Mar. 29-31, 22nd American Power Conference, co-sponsored by AIME, Hotel Sherman, Chicago.

Apr. 3-8, Sixth Nuclear Engineering and Science Conference, Coliseum, New York.

Apr. 4-6, AIME 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Palmer House, Chicago.

Apr. 19-22, International Symposium on the Metallurgy of Plutonium, sponsored by the Societe Francaise de Metallurgie and the French Atomic Energy Commission, Grenoble, France.

Apr. 21-22, Southwest Metals and Minerals Conference, Ambassador Hotel, Los Angeles, Calif.

Apr. 28-30, AIME Northwest Regional Conference, Sheraton Hotel, Portland, Ore.

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May 23-26, AIME Symposium on Refractory Metals and Alloys, McGregor Memorial Conference Center, Wayne State University, Detroit.

May 26-27, The Metallurgical Society, New England Regional Conference on *New Developments in Metalworking*, Statler-Hilton Hotel, Boston.

June 9-10, AIME Columbium Symposium, sponsored by the Hudson-Mohawk section, Hotel Sagamore, Lake George, N. Y.

June 13-15, First International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPIF.

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Resolving the driver-car-road complex

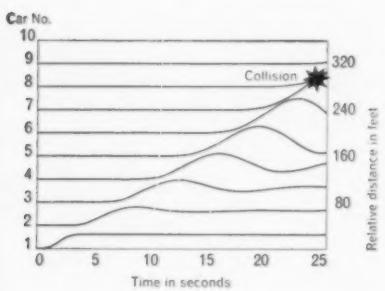
The manner in which vehicles follow each other on a highway is a current subject of theoretical investigation at the General Motors Research Laboratories. These studies in traffic dynamics, coupled with controlled experiments, are leading to new "follow-the-leader" models of vehicle interaction.

For example, conditions have been derived for the stability of a chain of moving vehicles when the velocity of the lead car suddenly changes – a type of perturbation that has caused multiple collisions on modern superhighways. Theoretical analysis shows that the motion of a chain of cars *can be stable* when a driver accelerates in proportion to the relative velocity between his car and the car ahead. The motion is always unstable when the acceleration is proportional only to the relative distance between cars. Experimentally, GM Research scientists found that a driver does react mainly to relative velocity rather than to relative distance, with a sensitivity of reaction that increases with decreasing distance.

Traffic dynamics research such as this is adding to our understanding of intricate traffic problems – what causes them, how they can best be resolved. The study is an example of the ways GM Research works to make transportation of the future more efficient and safe.

General Motors Research Laboratories

Warren, Michigan



Relative positions of 10 hypothetical cars after lead car goes through maneuver. Amplitude of instability increases, resulting in a collision between 7th and 8th cars.

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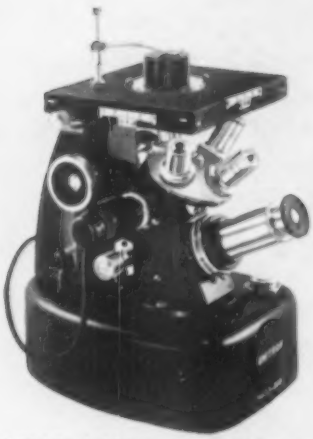

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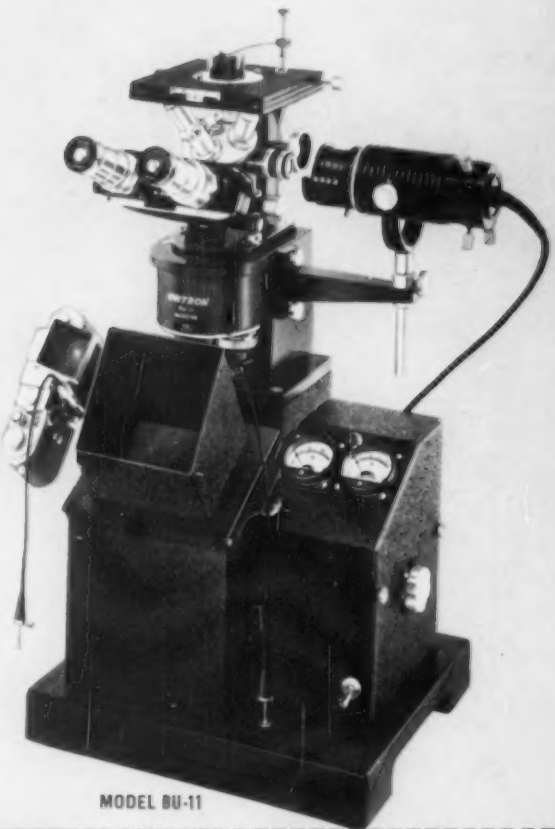

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